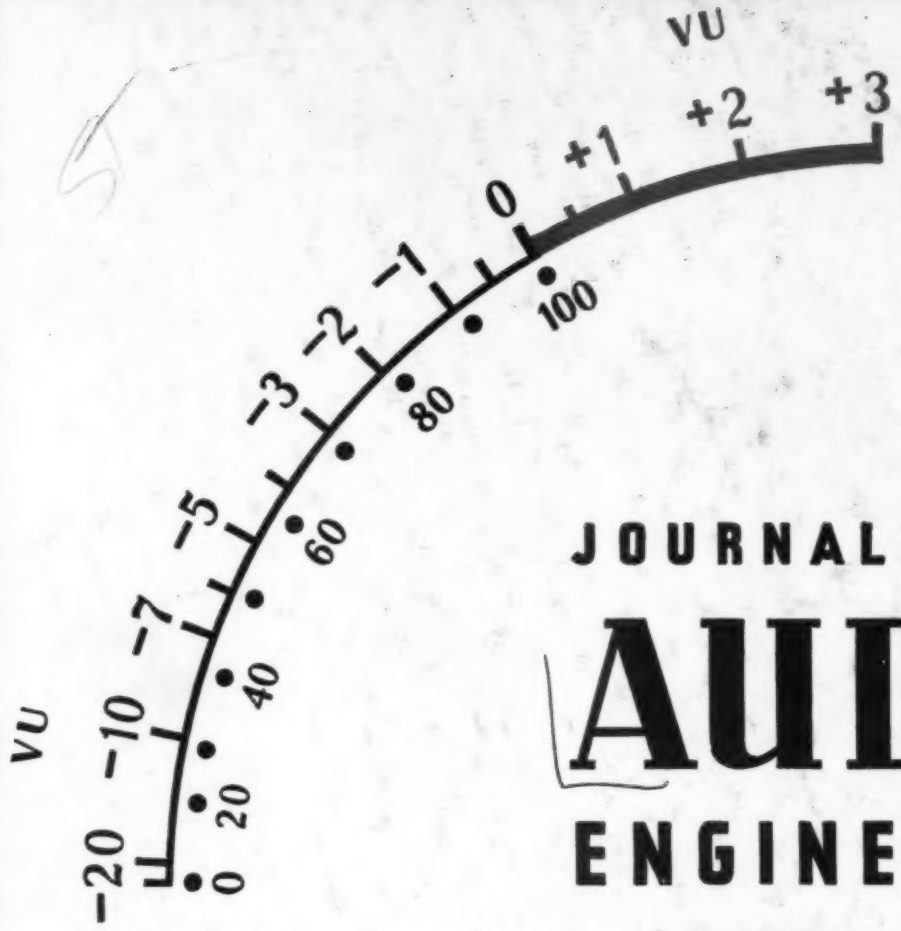

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10th ANNUAL CONVENTION ISSUE

Program and Abstracts

Also papers by

Barlow
Cares
Narma and Skov
Solomon and Broneer
Werner and Carrell
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de Miranda and van Zelst

VOLUME 6 NUMBER 4 OCTOBER 1958

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Constant-S Equalizers*

B. D. SOLOMON† and C. S. BRONEER‡

This paper presents analysis and design equations for a new and unique equalizer section called a *constant-S* equalizer. The uniqueness of this variable equalizer section is that as equalization is varied from step to step the apparent level of the program being equalized is constant. No compensating attenuators are employed. With conventional equalizers, as equalization is varied from step to step, the point of maximum equalization remains constant and the insertion loss of unequalized frequencies changes. With the *constant-S* equalizer, as equalization is varied from step to step, the point of maximum equalization changes and the insertion loss of unequalized frequencies remains constant.

INTRODUCTION

MODERN AUDIO systems require the maximum in versatility. Equalizers are important adjuncts to audio systems and for an equalizer to be versatile, it must be variable. Heretofore, most variable equalizers have been variable attenuators associated with appropriate reactive elements. This arrangement suffers from a fundamental defect in that as the equalization is varied, the apparent audio level of the program being equalized is also varied. This condition ensues because a variation in equalization is accomplished simply by changing the insertion loss of the attenuator associated with the equalizer. It is possible to place in series with this arrangement a compensating attenuator on the same shaft so that at all equalization settings the sum of the insertion losses of the attenuator associated with the equalizer and the compensating attenuator is constant. In this circumstance the apparent audio level of the program being equalized will remain constant but there is required the expense of an added attenuator. We shall here derive design equations for three basic types of variable equalizers which have constant resistance image impedances and which maintain constant insertion loss for unequalized frequencies from one equalization step to another. Only the bridged-T configuration is considered since the switching required is less complex than with other configurations also having constant resistance image impedances. The analytical methods employed are basically parallel to, although more complex than, those of Kimball[1] for fixed equalizers. It is shown that the maximum equalization step of the equalizers here presented is identical with the analogous Kimball section. This permits the use of the insertion loss curves included in Kimball's work.

The Kimball section is in reality a special case of a more general equalizer section which is here called a *constant-S* equalizer. S has been designated as the symbol for insertion loss in db. Obviously for an equalizer, S will be a function of frequency. The name constant-S equalizer has been given with some license to convey the idea that equalization may be varied while the program being equalized is maintained subjectively at a relatively constant average level. It is obviously not implied that the insertion loss is the same for all frequencies. The manner in which the equalized program is maintained at an apparently constant average level is that the larger portion of the audio spectrum which is not equalized encounters the same insertion loss for all equalizer settings. Only the insertion loss of the equalized portion of the spectrum changes from step to step. If in the design of a constant-S equalizer the larger portion of the audio spectrum is changed in level when equalization is varied, then the equalized program level is not maintained apparently constant, and this particular equalizer is not qualitatively a constant-S equalizer even though it may have the same configuration as some other truly constant-S equalizer. In conventional equalizers the insertion loss for unequalized frequencies is changed from step to step and the point of maximum equalization is held constant. In the constant-S equalizer, the insertion loss for unequalized frequencies is held constant and the point of maximum equalization is changed from step to step.

No dissipation in reactive elements has been considered in the analysis. With available toroidal inductors, excellent agreement can be obtained between the derived design equations and practice.

SYMMETRICAL BRIDGED-T EQUALIZER

The symmetrical bridged-T equalizer is essentially a Wheatstone bridge. Conventional representation of the bridged-T configuration is shown in Figure 1.

* Received March 28, 1958. Accepted April 23, 1958.
† Califone Corp., Hollywood, Calif.
‡ Studio Supply Co., Burbank, Calif.
[1] H. R. Kimball, *Motion Picture Sound Engineering*, D. VanNostrand Co., Inc., New York, 1938.

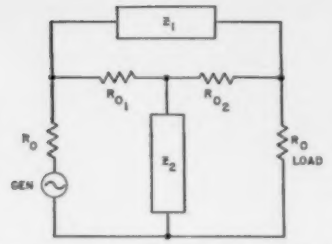

FIG. 1. Conventional representation of bridged-T equalizer.

R_0 is the characteristic impedance and Z_1 and Z_2 are generalized impedances. The symmetrical bridged-T equalizer may be arranged as shown in Figure 2.

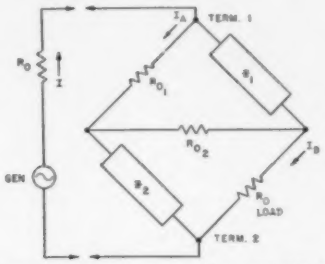

FIG. 2. Wheatstone bridge representation of bridged-T equalizer.

For bridge balance there will be no potential difference across R_{0_2}. Then:

$$\frac{R_{0_1}}{Z_2} = \frac{Z_1}{R_{0_{load}}} \quad \text{and} \quad Z_1 Z_2 = R_0^2.$$

This is the familiar relation for inverse impedances.

With the inverse relation and not having to consider R_{0_2}, the impedance which the generator sees may be shown by simple manipulation to be resistive and equal to R_0. Analogously, the load will also look into a resistive R_0. No matter the complexity of Z_1 and Z_2, the image impedances are still resistive and equal to R_0 provided only that $Z_1 Z_2 = R_0^2$.

Simple rules can be evolved for setting down the inverse of a given two-terminal network. For a capacitor, put an inductor. For an inductor, put a capacitor. For a resistance, put a resistance. For a parallel connection of one circuit element, put a series connection for its inverse, and, conversely. Each individual circuit element and its inverse are connected through the inverse relation.

Let insertion loss as a function of frequency be symbolized by S. Kimball derives the insertion loss in db of a bridged-T equalizer with inverse arms as[2]:

$$S = 20 \log [(R_0 + Z_1)/R_0]. \qquad (1)$$

[2] Kimball, *op. cit.*, p. 235.

The design equations for the bridged-T attenuator may be derived from this relation if it is considered that for this case Z_1 will be a resistance.

THE CONSTANT-S SECTION

We must now synthesize a structure which will meet the aforementioned constant-S conditions. Such a structure is shown in Figure 3.

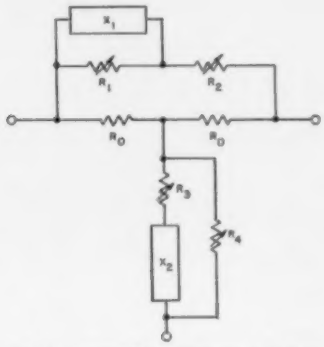

FIG. 3. Generalized constant-S section.

X_1 and X_2 are inverse reactances whose nature will be made clear later. On making appropriate substitutions in (1):

$$S = 20 \log \frac{R_1 (R_0 + R_2) + jX_1 (R_0 + R_1 + R_2)}{R_0 R_1 + j R_0 X_1}. \qquad (2)$$

The ratio involved is a ratio of two vector quantities. The magnitude of the insertion loss is the absolute value of this ratio,

$$S = 10 \log \frac{[R_1 (R_0 + R_2)]^2 + [X_1 (R_0 + R_1 + R_2)]^2}{R_0^2 (R_1^2 + X_1^2)}. \qquad (3)$$

X_1 in (3) is now only an absolute value for a given setting of equalization. There will be two extremes of insertion loss. The minimum insertion loss, or what is the same thing, the maximum equalization, will occur at the frequency such that X_1 is zero. Conversely X_2 will be an infinite reactance. The attenuator determining the loss at this frequency consists of R_2 and R_4 as well as the two R_0's. At the frequency for which X_1 is infinite and, conversely, X_2 is zero, maximum insertion loss ensues. The attenuator determining the maximum insertion loss consists of R_1 in series with R_2, R_3 in parallel with R_4, and the R_0's. The maximum insertion loss will hereafter be called the pad loss and the frequency at which minimum insertion loss occurs will be called the equalized frequency. For pad loss to remain constant from one equalization setting to another, it is seen that the resistance of R_1 and R_2 in series must remain constant as must the resistance of R_3 and R_4 in parallel. Equalization will

be defined as the difference between pad loss and the loss at the equalized frequency.

Insertion loss of an equalizer will be a function of frequency and will vary smoothly between the loss at the equalized frequency and the pad loss. The ratio of current delivered by a generator to current in the load under image impedance termination will be symbolized by K and obviously for a passive network, $K \geq 1$. Further, while K is defined as a positive quantity for manipulative ease, it is felt that from intuitive considerations, insertion loss should be shown graphically as a negative quantity. Ultimately a passive network cannot give—it can only take away.

In general, for insertion loss in db:

$$S = 20 \log K. \tag{4}$$

If K for pad loss is K_1 and K for loss at equalized frequency is K_2, then immediately, $K_1 \geq K_2$.

From a consideration of bridged-T attenuators:

$$R_1 + R_2 = (K_1 - 1) R_0, \tag{5}$$

$$R_2 = (K_2 - 1) R_0. \tag{6}$$

Consequently:

$$R_1 = (K_1 - K_2) R_0. \tag{7}$$

Making substitutions in (3):

$$S = 10 \log \frac{[R_0 K_2 (K_1 - K_2)]^2 + (X_1 K_1)^2}{[R_0 (K_1 - K_2)]^2 + X_1^2}. \tag{8}$$

At the frequency for which the reactance of X_1 is zero, the insertion loss becomes:

$$S = 10 \log K_2^2 \tag{9}$$

At the frequency for which the reactance of X_1 is infinite, the insertion loss becomes:

$$S = 10 \log K_1^2 \tag{10}$$

Quite apparently these respective insertion losses can be obtained also from a qualitative consideration of the definitions of the K's.

It is interesting now to compare (8) with Kimball's analogous expression.[3] At the setting for maximum equalization, called the top step, R_2 is zero and conversely, R_4 is infinite. The constant-S equalizer has degenerated into a Kimball section. For a Kimball section, K_2 will be seen to be unity and (8) is then Kimball's expression. The frequency for which insertion loss of our constant-S equalizer section is half-way between pad loss and loss at equalized frequency will be symbolized by f_B. The insertion loss at f_B is the arithmetic mean of the pad loss and the loss at equalized frequency. Alternatively, f_B is the frequency where the insertion loss is equal to half the equalization plus the insertion loss at the frequency of equalization. f_B will be called the frequency of half-equalization. Kimball has called f_B the half-loss or half-pad frequency and for the top step only of a constant-S equalizer, this is indeed the case. f_B is to an equalizer with finite pad loss what nominal cut-off frequency is to a filter. Taking the arithmetic mean of (9) and (10), the insertion loss at f_B is:

$$S_{f_B} = 10 \log K_1 K_2. \tag{11}$$

If (8) is put equal to (11), and X_1 is solved for, then in absolute value at f_B:

$$X_{1_B} = R_0 (K_1 - K_2) \sqrt{\frac{K_2}{K_1}}. \tag{12}$$

Again, when K_2 is unity, this expression becomes Kimball's expression.[4]

THE THREE TYPES OF EQUALIZATION

What shall be the nature of the reactances X_1 and X_2? This is contingent on the type of equalization desired. Only three types of equalization will here be considered. First, we would like to equalize low frequencies. This is shown in Figure 4:

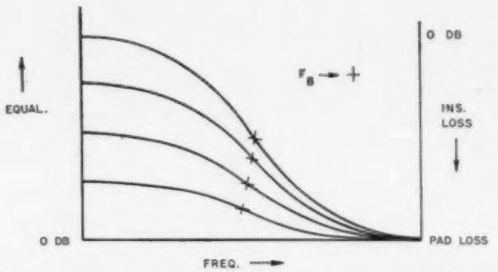

FIG. 4. Generalized response for low-frequency equalizer.

For qualitative constant-S conditions to hold, most of the audio spectrum should lie above the f_B's.

High-frequency equalization would also be desirable. This is shown in Figure 5:

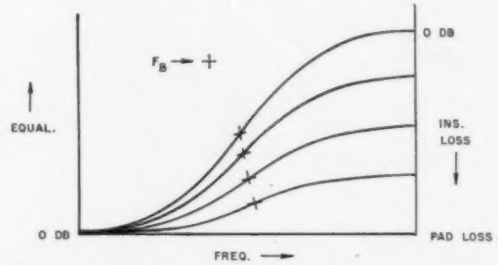

FIG. 5. Generalized response for high-frequency equalizer.

Most of the audio spectrum here should lie below the f_B's.

Mid-frequency equalization is the next consideration. This is shown in Figure 6:

[3] Kimball, *op. cit.*, p. 249.

[4] Kimball, *op. cit.*, p. 250.

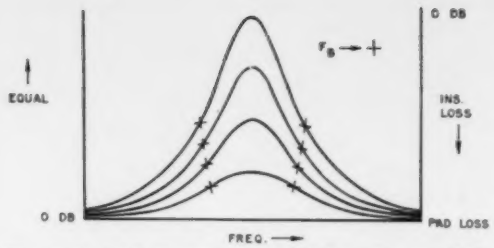

FIG. 6. Generalized response for mid-frequency equalizer.

Here most of the audio spectrum should lie both above and below the f_B's.

The simplest structures which the reactance X_1 can have to accomplish the desired equalization characteristics are: an inductor for low-frequency equalization, a capacitor for high-frequency equalization, and a series-tuned circuit for mid-frequency equalization. A parallel-tuned circuit for X_1 will not be considered in consequence of the type of equalization which would ensue. Most of the audio spectrum would be equalized and only the frequencies near resonance for the parallel-tuned circuit would remain at the pad loss from one equalization step to another. This does not fulfill the qualitative requirement for a constant-S equalizer notwithstanding a constant pad loss from one equalization step to another. For X_1 a series-tuned circuit, Figure 6 shows that only the frequencies near resonance are changed in insertion loss with a change in equalization.

For an inductor, reactance varies directly as frequency. Let X and f be respectively a generalized reactance and a generalized frequency and let X_B be the reactance of the inductor at f_B. Then: $X/f = X_B/f_B$, or

$$X = X_B(f/f_B). \tag{13}$$

For a capacitor, reactance varies inversely as frequency. Let X_B be the reactance of the capacitor at f_B. Again for X and f: $Xf = X_B f_B$, or

$$X = X_B(f_B/f). \tag{14}$$

For an equalizer where X_1 is an inductor, as in Figure 7, X_{1_B} as given by (12) is substituted in (13):

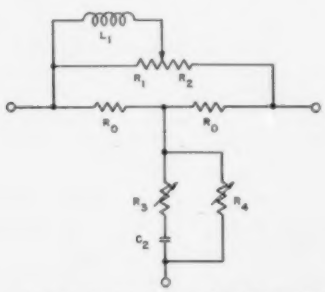

FIG. 7. Low-frequency constant-S equalizer.

$$X_1 = R_0(K_1 - K_2)\sqrt{\frac{K_2}{K_1}}\left(\frac{f}{f_B}\right). \tag{15}$$

Eq. 8 may be rearranged as:

$$S = 10\log K_2^2\left[1 + \frac{(K_1^2/K_2^2 - 1)}{1 + (K_1 - K_2)^2\,(R_0/X_1)^2}\right]. \tag{16}$$

On substituting for X_1 from (15) into (16), insertion loss in terms of design parameters is:

$$S = 10\log K_2^2\left[1 + \frac{(K_1^2/K_2^2 - 1)}{1 + \dfrac{K_1}{K_2}\left(\dfrac{f_B}{f}\right)^2}\right]. \tag{17}$$

For an inductor at f_B:

$$X_1 = 2\pi f_B L_1. \tag{18}$$

Setting (18) equal to (15) and solving for L_1:

$$L_1 = \frac{R_0(K_1 - K_2)}{2\pi f_B}\sqrt{\frac{K_2}{K_1}}. \tag{19}$$

Through the inverse relation: $X_1X_2 = R_0^2$ or $L_1/C_2 = R_0^2$, we get

$$C_2 = \frac{(K_1 - K_2)}{2\pi f_B R_0}\sqrt{\frac{K_2}{K_1}}. \tag{20}$$

For an equalizer where X_1 is a capacitor, as in Figure 8, the expression for X_{1B} from (12) is substituted in (14):

$$X_1 = R_0(K_1 - K_2)\sqrt{\frac{K_2}{K_1}}\left(\frac{f_B}{f}\right). \tag{21}$$

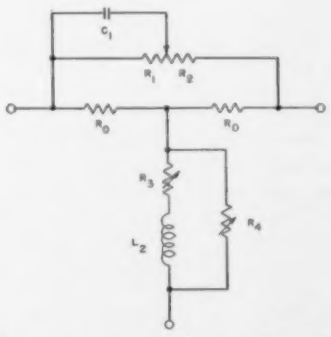

FIG. 8. High-frequency constant-S equalizer.

On substituting from (21) for X_1 into (16), insertion loss in terms of design parameters is:

$$S = 10 \log K_2^2 \left[1 + \frac{(K_1^2/K_2^2 - 1)}{1 + \frac{K_1}{K_2}\left(\frac{f}{f_B}\right)^2} \right]. \quad (22)$$

For a capacitor at f_B:

$$X_1 = \frac{1}{2\pi f_B C_1} \quad (23)$$

Setting (23) equal to (21) and solving for C_1:

$$C_1 = \frac{\sqrt{K_1/K_2}}{2\pi f_B R_0 (K_1 - K_2)}. \quad (24)$$

Through the inverse relation:

$$L_2 = R_0^2 C_1 = \frac{R_0 \sqrt{K_1/K_2}}{2\pi f_B (K_1 - K_2)}. \quad (25)$$

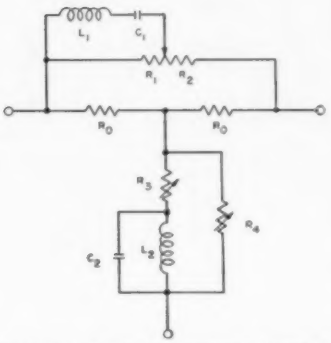

FIG. 9. Mid-frequency constant-S equalizer.

Consider now an equalizer where X_1 is a series tuned circuit as in Figure 9. Let f_R be the frequency of resonance of X_1. The resonant frequency of X_2 will be also f_R.

Define: $$B = f_R/f_B \quad (26)$$

with $$B > 1. \quad (27)$$

Eq. (27) implies that of the two possible f_B's (See Figure 6), the f_B less than f_R is chosen.

Kimball[5] has derived for X_1:

$$X_1 = X_B \frac{\frac{f}{f_R} - \frac{f_R}{f}}{B - \frac{1}{B}}. \quad (28)$$

Substituting X_{1_B} from (12) into (28):

$$X_1 = R_0 (K_1 - K_2) \sqrt{\frac{K_2}{K_1}} \left[\frac{\frac{f}{f_R} - \frac{f_R}{f}}{B - \frac{1}{B}} \right]. \quad (29)$$

On substituting from (29) for X_1 into (16), insertion loss in terms of design parameters is:

$$S = 10 \log K_2^2 \left[1 + \frac{\frac{K_1^2}{K_2^2} - 1}{1 + \frac{K_1}{K_2}\left[\frac{B - \frac{1}{B}}{\frac{f}{f_R} - \frac{f_R}{f}} \right]^2} \right]. \quad (30)$$

In a series tuned circuit, Kimball[6] has derived for L:

$$L = \frac{X_B}{2\pi f_B} \frac{1}{B^2 - 1}, \quad (31)$$

and for C:

$$C = \frac{1}{2\pi f_B X_B} \frac{B^2 - 1}{B^2}. \quad (32)$$

Substituting for X_{1_B} from (12) into (31):

$$L_1 = \frac{R_0 (K_1 - K_2)}{2\pi f_B} \sqrt{\frac{K_2}{K_1}} \left(\frac{1}{B^2 - 1} \right). \quad (33)$$

Substituting for X_{1_B} from (12) into (32):

$$C_1 = \frac{1}{2\pi f_B (K_1 - K_2) R_0} \sqrt{\frac{K_1}{K_2}} \left(\frac{B^2 - 1}{B^2} \right). \quad (34)$$

Through the inverse relation:

$$L_2 = \frac{R_0}{2\pi f_B (K_1 - K_2)} \sqrt{\frac{K_1}{K_2}} \left(\frac{B^2 - 1}{B^2} \right), \quad (35)$$

and

$$C_2 = \frac{1}{2\pi f_B R_0} (K_1 - K_2) \sqrt{\frac{K_2}{K_1}} \left(\frac{1}{B^2 - 1} \right). \quad (36)$$

For all equalizer sections considered, R_1 and R_2 are given by (7) and (6) respectively.

By the inverse relation:

$$R_3 = \frac{R_0}{K_1 - K_2}, \quad (37)$$

and

$$R_4 = \frac{R_0}{K_2 - 1}. \quad (38)$$

[5] Kimball, *op. cit.*, pp. 217, 253.

[6] Kimball, *op. cit.*, pp. 217, 254.

Element values and insertion loss in db have been derived for three types of constant-S equalizers in terms only of design parameters and appropriate constants. While not every contingency in practice can be accounted for by the equalizer sections here presented, many nonetheless can. Consequently, a brief outline of design procedure may prove helpful. First, the maximum amount of equalization should be fixed. The characteristic resistance is implicit. Pad loss should equal maximum equalization. It is improvident to make pad loss any greater than maximum equalization although this is entirely possible. The type of equalizer section should be decided upon and an f_B chosen for the top step. This choice is dependent on the portion of the audio spectrum it is desired to equalize. A help in this respect is provided by Kimball[7] in a series of charts which are applicable to the top step if the maximum amount of equalization is equal to pad loss. It is well to keep in mind that Kimball plots insertion loss in the positive direction. Equalization steps below the top step are chosen and the resistors directly calculated. Reactances are usually calculated at the top step where an f_B has been chosen and where K_2 is unity if the maximum amount of equalization is equal to the pad loss. Reactance formulae show how f_B varies with K_2, given K_1, R_0, and, if applicable, B.

An interesting possibility occurs when it is desired to have specific equalization steps at some particular frequency other than zero frequency, infinite frequency, or resonant frequency in the respective low-, high-, or mid-frequency equalizer. More particularly, it is necessary to know the specific K_2 corresponding to a particular frequency at the specific equalization step. This K_2 may be obtained from the applicable insertion loss formula and the formula for any particular reactance in the equalizer section. After designing the equalizer for the top step, all parameters including the insertion loss for a step off the top step will be known with the exception of K_2 and the f_B for this step. These two unknown parameters also appear in every reactance formula for every section. It is only necessary to solve simultaneously for a particular section, the insertion loss formula and a reactance formula to obtain the appropriate K_2. Demonstrably, all derived design equations degenerate to those of Kimball at the top step where K_2 is unity. Also, the greatest rate of change of insertion loss occurs at f_B. This may be shown by taking the second derivative of any insertion loss formula with respect to f, setting this equal to zero, and solving for the independent variable f. f_B is also coincidentally a point of inflection.

[7] Kimball, *op. cit.*, pp. 262-272.

CONCLUSION

We have here presented design equations for three types of constant-S equalizers. The necessary switching can be accomplished with only three brushes, if it is recalled that the sum of the resistances in the series arm is constant for all equalization steps. Only one brush is required to contact the junction of these resistances. The arrangement involving a conventional equalizer and a compensating attenuator requires at least four brushes for four variable resistors. The constant-S equalizer affords not only an economy of components over the conventional arrangement but also an economy of design effort.

THE AUTHORS

Bertram D. Solomon was born in Miami, Fla. on Nov. 21, 1925. He attended the University of Miami and while there was made a member of the Engineering Honor Society and Pi Mu Epsilon, a national mathematics honorary fraternity. He graduated in 1952 with a B.S.E.E. For the next two years he attended the graduate school of the University of Miami studying physics and working on an Army Ordnance research contract in design and development of electronic instrumentation.

In California Mr. Solomon has been associated with Collins Radio Co. in design and development of transistorized terminal equipment for digital data transmission systems, with Cinema Engineering Division of the Aerovox Corp. in the design of audio networks and special products, and with the Califone Corp. in the design and development of magnetic tape recorders.

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Charles S. Broneer was born in Hermosa Beach, California, in 1924. He received his B.S. degree in engineering from the University of California at Los Angeles in 1952. As an undergraduate he was employed by the Cinema Engineering Company in their engineering department where he invented the confluent equalizer. After graduation he went on to become chief engineer for Cinema, then a division of the Aerovox Corporation. In 1957 he was in charge of magnetic components design for the Electra Division of Consolidated Electrodynamics Corporation. At present he is vice-president in charge of engineering for Studio Electronics Corporation, Burbank, California, manufacturers and distributors of professional sound and recording equipment.

Mr. Broneer is a member of the AES and the Hollywood Sapphire Group.

The Limiting Tracking Weight of Gramophone Pickups For Negligible Groove Damage*

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It has been observed that when spherical styli are dragged over flat vinyl surfaces, scratches are produced under loads considerably exceeding the elastic limit as calculated from theory. The author, in this paper, describes the results of his experiments which bear out his argument that under load the point of yield begins below the surface; and reaches the surface, producing visible tracks, only after the calculated yield load is exceeded.

This critical value of load for styli of various radii has been measured and found to be equivalent to, for a 1-mil stylus, 0.64 gm. for a 90° record groove. No size or skin effect was found with the vinyl material tested.

INTRODUCTION

IN A recent paper(1), Prof. F. V. Hunt described scratch tests in which 1 mil and 3 mil radius styli were dragged over flat vinyl surfaces. There was a critical load below which no track was observed. This limiting load was very much greater than the elastic limit, calculated from the Hertz equations for the contact of a sphere with a flat surface, and Hunt therefore suggested that the vinyl material exhibited a size effect, such that small volumes of material, like that in contact with a stylus, would have a higher elastic limit than the bulk material. The present author has argued(2) that this size effect is unlikely and is an unnecessary hypothesis, and that Hunt's results represented the expected behavior of a material under a spherical indenter. Thus, at the calculated yield load, the point of yielding is below the surface, the surface remaining elastic; as the load is increased, the yielded area spreads and will eventually reach the surface and produce visible tracks at some very much higher load, this being the limiting load which Hunt observed. The present paper describes loading tests in support of this. The practical importance of this critical load is obvious, as it represents the limiting tracking load below which damage done to the record groove wall will be negligible.

LOADING TESTS

The author has suggested(3) that the limiting load for no surface plastic deformation of a flat vinyl surface by a 1 mil radius stylus is above 0.33 gm from theoretical considerations and below 0.75 gm from Hunt's results, corresponding to 0.4 – 1 gm for a 90° record groove. The following tests were carried out to determine this load more accurately.

A 1 mm radius hardened steel Brinell ball was used as the indenter on pieces cut from vinyl records, although if large slabs of vinyl had been available, a larger radius indenter would have been used. The sphericity of the ball was checked at numerous points under the interference microscope, as a slight flat would have seriously affected results. The loads ranged from 1 gm to 15 kg, thus covering the fully plastic, intermediate, and elastic ranges. Loads of 5 kg and above were applied by means of a Vickers hardness testing machine; lower loads were applied by means of direct loading of a lever, sensitive to about 5 mg at the lower loads.

By applying a thin surface film, *e.g.*, of carbon or metal, the total contact area (plastic + elastic) under load is given by the area of film removed by the indenter. A vacuum deposited aluminum film, about 1000 A.U. thick, was found to give a readily visible track, although it is open to the possible objection that the film might be hard enough to influence results at low loads. Another possible objection to this method is that electrostatic attraction may cause particles from the film immediately adjacent to the contact area to adhere to the indenter, giving a high value for the track width; this seems unlikely and could doubtless be avoided by earthing the indenter where this is conducting. A further and more serious objection is that results will be inaccurate when the impression depth approaches the film thickness; in the present case, this only occurs below about 10 gm load on the 1 mm radius indenter, which is below the range in which the chief interest lies. It was found that by smearing a finger over the surface, a satisfactory thin film of grease was formed, on which traces could be readily detected; Fig.

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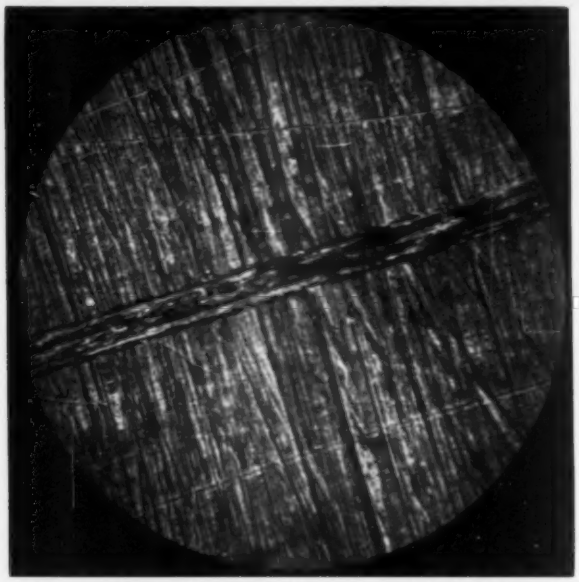

FIG. 1. Photograph of (elastic) track on vinyl left by 1 mm radius indenter under 1 gm load. Magnification × 250.

1 shows the trace given by a 1 gm load on the 1 mm radius indenter. The film thickness, as measured on the interference microscope, was about 1,000 A. U. By dissolving off the film with petroleum ether, the plastic tracks only were left and could then be measured. The grease served as an adequate lubricant to prevent pickup, as it was found that without a lubricant, a frictional trace, doubtless of particles of welded-on steel, could be seen on the vinyl even at the lowest loads, so that the distinction between elastic and plastic tracks was not clear.

In carrying out the tests, loading was started from the lowest load, so that grease adhering to the indenter from wide tracks would not affect the track width seen at lower loads, although a check starting from the highest load gave similar results, showing that this effect was not serious. The record was traversed slowly at each load, and the track width measured rather than the impression diameter, thus avoiding errors due to the impact of the indenter when being loaded, a frequent source of error in micro-hardness testing. At the higher loads (5 kg and above) where the Vickers machine was used, this type of error is negligible, and the impression diameter was measured in the usual way. All measurements were taken by means of the measuring microscope of the Vickers machine, the sensitivity being $1 - 0.2\ \mu$, according to the objective used (⅔", ¼", and ⅙"). The means were taken of three sets of tracks and a check on a record from a different source gave similar results. For comparison purposes, results were expressed in terms of the equivalent values for a 1 mil radius indenter. In Fig. 2, equivalent track widths, both total and plastic, are plotted against equivalent load. No plastic tracks were visible at 0.45 gm and a trace could just be observed at 0.52 gm, although as with all plastic traces at low loads, the edges are not sharp. The limiting load for a 1 mil stylus may therefore be taken as about 0.45 gm, corresponding to 0.64 gm for a 90° record groove. Fig. 3, taken under oblique illumination, shows typical plastic tracks at equivalent loads of 1.29, 0.97, 0.64 gm, disappearing at 0.45 gm. Fairly large shallow tracks such as these, are often more easily detected by the naked eye than by the microscope, and are not easily photographed. Small changes in surface contour are known to be sensitive to phase-contrast illumination, but unfortunately this was not available.

It is interesting to note in passing, that a powerful light source, *e.g.* an arc, used on a projection microscope, produces sufficient heat to cause annealing of the vinyl at low magnifications and melting at higher magnifications, in spite of the presence of the water cell, which is supposed to absorb the heat. On metal specimens, no trouble is experienced, doubtless due to the high thermal conductivity, but for vinyl, the exposure time was limited to about 10 minutes at the lower magnifications. The effect of annealing on vinyl and many other plastics is to cause the plastically deformed molecules to revert to their original positions, *i.e.* plastic tracks disappeared leaving a flat surface almost unchanged from the original. This suggests a possible method of reconditioning damaged records.

SIZE EFFECT

In order to determine if there was a size effect, loading tests were repeated on 2.5 and 1 mil radius sapphire styli, and the plastic track width results are plotted for comparison in Fig. 2. It will be seen that within the expected scatter of results, there is no size effect, although the point at which tracks dissappeared is less easy to detect on a small scale.

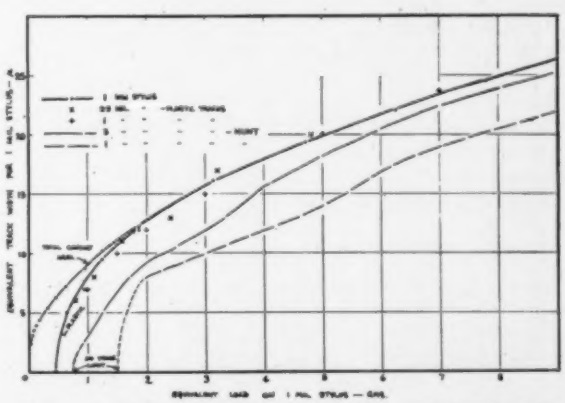

FIG. 2. Graph of equivalent track width *vs* equivalent load for 1 mil radius stylus on vinyl.

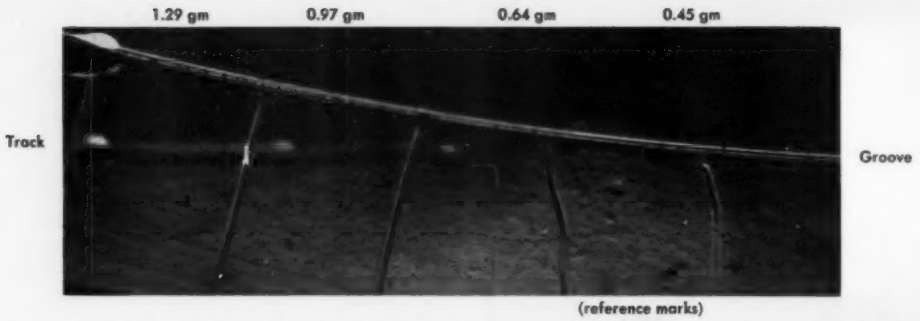

FIG. 3. Photograph of plastic tracks on vinyl, left by 1 mm radius indenter under equivalent loads on 1 mil radius stylus of 1.29 gm, 0.97 gm, 0.64 gm, disappearing at 0.45 gm. Magnification × 10.

The contact pressure, calculated as $\frac{4 \times \text{load}}{\pi \times (\text{track width})^2}$ kg/mm^2, versus the load is plotted in Fig. 4 for both total and plastic track widths. It will be seen that if the total contact area under load is taken, the curve passes through the origin, as would be expected. However, if the plastic track width only is taken, the curve takes a sharp upward turn with decreasing load; this again is to be expected, as, if the load is low enough, the stresses will be entirely within the elastic range, there will be no plastic track and a meaningless value of infinity will be obtained for the contact pressure or hardness. It seems that this apparent increase in hardness or contact pressure with decreasing load led Hunt to suggest the size effect theory.

Hunt's results are plotted for comparison in Figs. 2 and 4, and are appreciably different from the present values. This may be due to the materials being from different sources, Hunt's material being generally harder. However, although there is no size effect in the present material, and although the apparent increase in hardness at low loads is seen to be a bogus one, the fact remains that under the 1 mil stylus, Hunt's vinyl is harder than under the 3 mil indenter. This might be a skin effect. Thus if the skin of the vinyl is harder than the interior, the shallow impressions of the 1 mil stylus will give a greater hardness than the deeper impressions of the 3 mil stylus. For a comparison between impressions of different widths and depths, an indenter giving geometrically similar impressions at all loads must be used. The Vickers diamond pyramid is one such indenter (this consists of a square pyramid with an included angle of 136° between opposite faces). This was used on the present material with loads of 1–50 gm, the diagonals of the pyramid being at 0° and 90° to the track, Fig. 5. The contact pressure was calculated as $\frac{2 \times \text{load}}{(\text{track width})^2}$ and values are plotted in Fig. 6. This shows that there is no skin (or size) effect in the present material. As the Vickers diamond is sharp, impressions at all loads are in the fully plastic range, where all the material in contact with the indenter is plastic, and

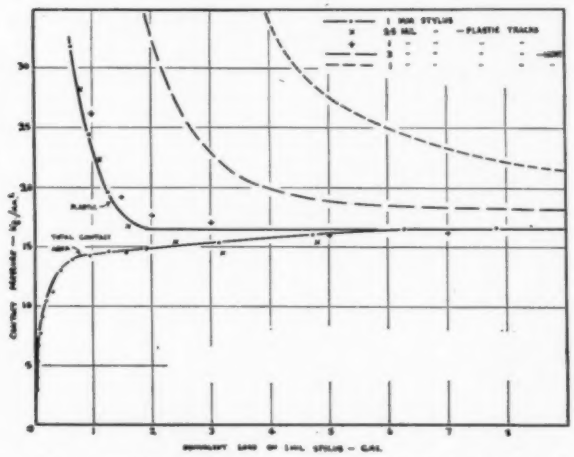

FIG. 4. Graph of contact pressure *vs* equivalent load for 1 mil radius stylus on vinyl.

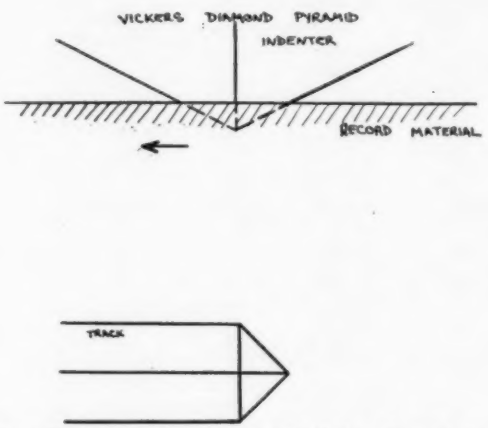

FIG. 5. Mode of producing tracks with Vickers diamond pyramid indenter.

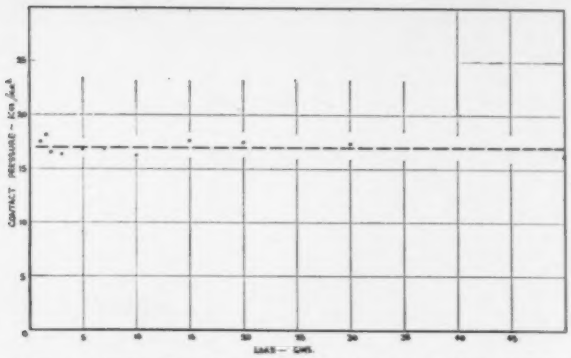

FIG. 6. Graph of contact pressure *vs* load on Vickers diamond pyramid indenter on vinyl.

reliable and comparable hardness values are obtained at all loads; values are always slightly higher with a pyramid than with a spherical indenter.

A harder skin on vinyl could arise in two possible ways. Thus, mechanically polishing the surface might give a work-hardened or oriented layer. Alternatively, in molding, the different conditions at the surface of the mold might give rise to an oriented or more highly polymerised skin; where a plasticizer is used, it is known that under some conditions, a hard skin can be obtained due to the plasticizer at the surface being depleted or rendered ineffective, although the grades of vinyl used for records do not usually contain a plasticizer.

MECHANICAL TESTS

The mechanical properties of the material used in these tests were determined from tensile and bend tests on small test pieces cut from the record. The yield stress coincided with the ultimate tensile stress, after which the material necked down considerably before fracture. The neck formed at one point and then travelled along the test piece at constant load until fracture. The sudden yield and the fibrous appearance of the fracture were doubtless due to the orientation of the previous random molecules, as occurs with some other plastics. The elastic modulus was obtained from a bend test, using a simple cantilever and measuring the deflection with a travelling microscope. This was much more accurate than direct measurement on a tensile test piece, where the accuracy is limited by the short gauge-length and the lack of reliable small extensometers. Values of 300 kg/mm^2 for the modulus and 4.75 kg/mm^2 for the yield stress were obtained, which agree with the plastic manufacturers data, giving the calculated limiting elastic load for a 1 mil stylus on a flat surface of 12.6 mg, compared with Hunt's value of 11 mg.

CONCLUSIONS

1. The increase in hardness with decreasing load reported by Hunt is an apparent one only, due to using the plastic instead of the total contact area in calculating the hardness.

2. The elastic limit of the present material is about 13 mg with a 1 mil radius stylus on a flat surface; the limiting load for all plastic deformation to remain subsurface is about 0.45 gm, corresponding to 0.64 gm for a 1 mil stylus in a 90° record groove.

3. A size effect hypothesis is unnecessary, as the vinyl behaves as would be expected under a spherical indenter.

4. Loading tests with 1 mil, 2.5 mil, 1 mm radius, and pyramid indenters show that there is no size or skin effect on the present material.

5. The differences between Hunt's results for the 1 mil and 3 mil radius styli might be due to the skin of his material being harder than the interior.

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Mismatch Between Power Amplifiers and Loudspeaker Loads*

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Audio power amplifiers are usually designed to deliver rated power at low distortion into a fixed resistive load. Loudspeakers present to the amplifier a frequency-dependent impedance which is usually not a resistance equal to the nominal impedance of the loadspeaker. The volt-ampere characteristics of amplifiers under impedance mismatch conditions are illustrated. The effects of negative voltage and current feedback are shown as they affect the distortion of the amplifier while operating into other than rated load impedance.

SUPERIOR quality sound reproduction depends on the degree of match between amplifier and loudspeaker. Certain problems of amplifier design and their effect on transfer of maximum sinewave power to a loudspeaker load are discussed. It is hoped that this effort might assist loudspeaker designers in improving future designs by allowing for inherent limitations of amplifier capabilities.

The most common and usually the most complex load presented to an audio power amplifier is the load presented by a loudspeaker system. The measured impedance of a nominal 16-ohm loudspeaker may vary between 4 and 250 ohms at various frequencies and is usually not resistive. These figures are the extreme figures, not representative of any one particular loudspeaker, but these are the values that an amplifier designer has to take into consideration. The reasons for these large impedance variations are at this time inherent in loudspeaker design. This variation in impedance is often counted on by loudspeaker designers to vary the frequency response of a loudspeaker or loudspeaker system to meet certain frequency-response specifications.

At this point it may be worthwhile to review some of the methods used by loudspeaker designers, showing their relation to amplifier design. The usual goal is to have the loudspeaker frequency response as flat as practical, which is in many cases obtained by one or more loudspeakers in the system. Frequency-response measurement of loudspeakers is usually performed with amplifiers operating well below overload. In this case the amplifier may be considered to act as a voltage generator of adjustable internal impedance. It is known that the frequency response of loudspeakers can be varied by varying the internal impedance of the amplifier. The ratio of rated load impedance to internal impedance of the amplifier is defined as the damping factor of the amplifier. The rated impedance of a loudspeaker is usually defined as the minimum impedance value which is found at a frequency higher than that of the cone resonance frequency but still in the operating frequency range of the loudspeaker. Fig. 1 shows the impedance variation, with respect to frequency, of a typical high-fidelity loudspeaker in an infinite baffle.

When measuring loudspeakers the amplifier is usually operated at fairly conservative levels and is usually not overloaded. However, when the limitations of an amplifier are desired to be found, this amplifier will be operated close to overload conditions. It is the purpose of this article to illustrate how a mismatched load connected to an amplifier affects the maximum available output of the amplifier itself. To analyze such a condition a few fundamental relations have to be taken into account. The usual limitation in operation of a power amplifier, of course, is that of the output tubes. These output tubes act as a variable resistance between the load impedance and the power supply. For any given load, the maximum instantaneous current into the load impedance, and the maximum voltage drop across that load, occur when the grid voltage of one of the output tubes is at zero and the tube begins to draw grid current. In case the output tube is dc coupled to an earlier stage, then the same condition exists when the driver stage grid voltage is zero. The maximum instantaneous plate-voltage swing is limited by the power supply voltage. The maximum available current is limited by the tube perveance. The maximum output power, or output volt-amperes, occurs when the product of output voltage and output current are maximum. This is not necessarily the point of lowest distortion. For the purpose of this analysis it is assumed that the output wave-

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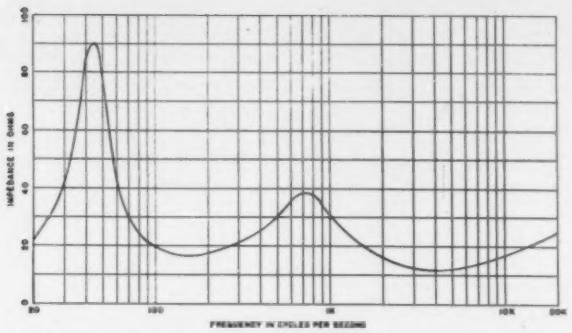

FIG. 1. Impedance *vs* frequency of a typical 16-ohm loudspeaker.

forms, both voltage and current, are kept sinusoidal by sufficient feedback from the output terminals back to an earlier amplifying stage of the amplifier. This circuit is representative of most high fidelity amplifiers. For the purpose of this analysis it will be assumed that the output transformer is an ideal transformer, only transforming the rated load resistance to the desired tube load resistance without insertion loss or distortion.

With these assumptions in mind, the performance of an amplifier can be analyzed using graphical methods to determine output power or output volt-amperes. Here it is assumed that an amplifier has been constructed with two 6L6 tubes in push-pull tetrode connection, using regulated plate, screen and bias supplies. The plate voltage selected is 350 volts, the screen voltage 250 volts, the bias for the first grid 20 volts. This results in a plate current of 44 ma per tube under no-signal conditions, resulting in a plate dissipation of approximately 15.5 watts. Fig. 2 shows the plate characteristics of this tube.

In Fig. 3, the curves for both tubes have been combined into the effective push-pull connection. The voltages and current shown on this figure are the instantaneous values occurring across a load impedance connected between one plate and the power supply. The other lines on the same figure indicate the operating conditions with purely resistive, purely reactive, and combination reactive-resistive loads. These curves are drawn so as to show maxmum permissible grid drive under these given load conditions. It can be seen that these three loads touch the line which corresponds to zero grid voltage on one tube, or a total grid swing of 40 volts peak-to-peak. These curves are drawn under the assumption of an ideal output transformer, one having no losses or no winding resistance.

If a number of load curves are drawn for resistive and reactive loads, the maximum output voltage and output current can be found with each load. The results of this are shown in Fig. 4. Here, maximum output voltage is plotted against maximum output current for both resistive and purely reactive loads. With reactive loads, voltage and current are at a 90° phase angle to each other and the amplifier delivers no power. If the load is both resistive and reactive, the maximum output will fall somewhere in between those two lines. The point marked with a circle on these curves is that point corresponding to the maximum output power in the case of resistive load, or maximum output volt-amperes in the case of reactive load. It may be seen that for these tubes the maximum short-circuit current is only approximately 20% higher than the current available into the rated load. The assumption is that the rated load is the value of resistance resulting in maximum available output power. The curves of Fig. 4 show that the maximum open-circuit voltage is only approximately 12% higher than that existing under rated load conditions.

The data of Fig. 4 have been replotted in Fig. 5. Here, maximum output power and maximum output volt-amperes are shown with respect to plate-to-plate load impedance. Again these curves show the conditions for only resistive or purely reactive loads. Examination of these curves shows some other interesting results. If it is assumed that this amplifier is designed to feed a 16-ohm loudspeaker and therefore has an output transformer matching 8,000 ohms to 16 ohms, then an output power of approximately 24 watts could be obtained into a resistive load of 16 ohms. If a loudspeaker with wide impedance variations is connected as load to this amplifier a serious reduction in power output would be found. No amount of inverse feedback would increase that power output. For example, a resistive load of 4 ohms could receive a power no higher than 9 watts, whereas a resistive load of 250 ohms could receive no more than 2 watts. Following usual practice, this amplifier would be rated as a 20 or possibly even 24 watt amplifier.

Up to this point only the question of maximum available output has been covered. As stated earlier, it is assumed that this amplifier has been constructed with a sufficient amount of feedback so as to keep the output waveform sinusoidal with sinusoidal input signal. Also, it has been assumed that the input voltage to this amplifier has been adjusted so as to give maximum output. This is generally not the case under normal operating conditions. Here, input voltage to the amplifier is generally kept constant, and the magnitude of

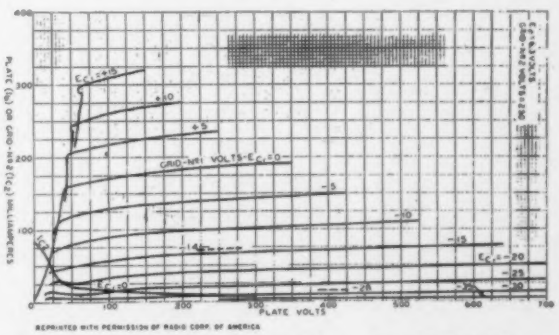

FIG. 2. Average plate characteristics of type 6L6-GB tube.

load impedance varies throughout the frequency range. If the type of feedback in this amplifier is mostly voltage feedback and it is assumed that a damping factor of 10 has been achieved, then removal of the rated load would result in an output voltage rise of 10%. This value is still below the maximum available output voltage. However, if the output impedance is decreased by a factor of 2 then the output tubes will be overdriven because this amplifier is not able to produce an output current which is twice as high as the rated output current.

The converse is true if this amplifier has been constructed with a liberal amount of current feedback so as to result in a damping factor of 0.1. Here a change in load impedance from rated load to zero or short-circuit load will result in an output current only 10% higher than that existing with rated load. This value is still smaller than the maximum output current available under short-circuit conditions, and therefore the output current waveform will be sinusoidal. Increasing load impedance by a factor of 2 will produce serious distortion because the available output voltage is smaller than that which would be required by Ohm's law. On Fig. 4 a number of lines have been drawn to show the interdependence of maximum available load voltage and maximum available load current as the load resistance is varied. A particular load line has been drawn. An ideal generator produces maximum output power when the load impedance is identical to the source impedance which is determined by the ratio of open-circuit voltage to short-circuit current. Therefore it can be concluded that an amplifier performs as an ideal generator with a given internal impedance only well below the point of maximum output. There is only one narrow range of load resistances which results in maximum available output power. This range of values is independent of the internal impedance of this amplifier. If it is assumed that all high quality amplifiers have a liberal amount of feedback incorporated in their circuitry, then variation of internal impedance can only be accomplished by properly proportioning both current and voltage feedback. Regardless of what type of feedback is applied, the output power for any given load will not be changed.

Under no circumstances will an amplifier be capable of matching all load impedances without loss of output power unless the turns ratio of the output transformer is adjusted for best matching at each frequency, which is impossible. There is only one value of load resistance which results in maximum output power. A range of load impedances varying in the ratio of 2 to 1 can be connected to such an amplifier if an output loss of approximately 20% is tolerable at the extremes of this range of load impedances. This is fundamental and no fancy circuit can compensate for this loss, and there is no type of circuit which will automatically match an amplifier over a range of impedances.

High fidelity amplifiers are generally constructed with an output transformer so that rated load resistances of 4, 8, or 16 ohms can be connected. These amplifiers behave the same way as the theoretical amplifier shown above. In actual amplifiers some additional factors must be considered. First, a wider range of frequencies must be handled. In the earlier discussion only the absolute value of reactance and resistance was considered. Capacitive reactance for a given capacitor

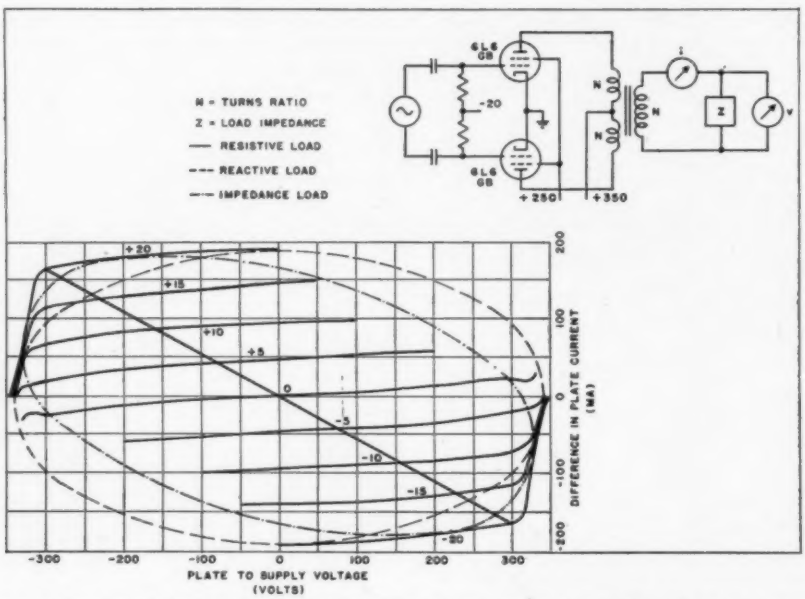

FIG. 3. Characteristic load diagrams for three types of load presented to 6L6-GB tubes in push-pull.

decreases with frequency, whereas inductive reactance of a coil increases with frequency. Within the normal operating frequency range of an amplifier, variation in load impedance causes no difficulty other than a decrease in maximum obtainable output power. The practical difficulty arises at frequencies which are either higher than the maximum operating frequency of the amplifier or lower than the lowest operating frequency of the amplifier. Here, phase shift of the reactance load will cause a proportionate amount of phase shift in the feedback signal applied to earlier stages of the amplifier. Under these circumstances, amplifier instability may result because this amplifier may have been designed with only marginal phase stability. Since the amplifier designer usually has no control over the magnitude and phase angle of the load connected to the amplifier he has to design the equipment so that in no case can oscillation occur with loads varying in magnitude from zero to infinity, and in phase angle from –90 to +90 degrees. It also may be possible that the amount of feedback will change when the amplifier is driven to higher output levels. Under these circumstances an amplifier which may have been stable at low output power levels, may become unstable during a portion of the time and possibly will show oscillation during part of the cycle of the driving voltage. The requirement for high stability with inverse feedback usually will result in a reduced frequency range for the amplifier.

From a practical standpoint, voltage feedback is the type of feedback most readily incorporated in a power amplifier. Here, depending on the output transformer, a reasonable minimum amount of phase correction has to be applied to the feedback loop. Low feedback power is usually required and feedback can be applied to a stage operating at a reasonable signal voltage level. (Order of magnitude of a few volts.)

Application of current feedback is usually somewhat more difficult. In order to achieve a relatively small loss in output power a small series resistor has to be connected between the output transformer and the load. The voltage drop

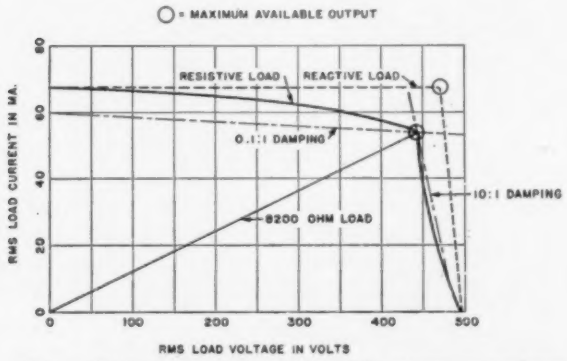

FIG. 4. Maximum available plate-to-plate current *vs* maximum available plate voltage.

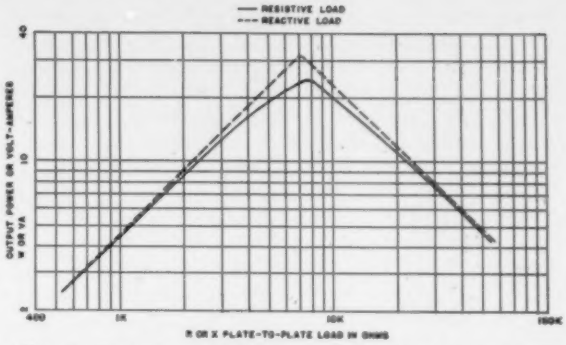

FIG. 5. Maximum available volt-ampere output *vs* load impedance.

across this resistor is fed back to a stage operating at a similar voltage level. This voltage is usually a fraction of a volt and requires feedback to a stage earlier in the circuit than that necessary for voltage feedback. The higher number of amplifying stages enclosed in this feedback loop will result in a higher total phase shift which must be corrected in the feedback loop. Rather extensive phase compensation is required, resulting in an even more restricted frequency range for a given output transformer and for the same degree of phase stability of the amplifier with the same large variation in load. A further disadvantage is that one side of the output load impedance cannot be grounded whenever there is an even number of stages of amplification in the feedback loop and cathode feedback is used.

All the foregoing discussion leads to something which might be called a set of goals for the loudspeaker designer as desired by the amplifier designer. Aside from the wide fre-

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He joined H. H. Scott, Inc. in 1951, where his duties as Chief Research Engineer include technical responsibility for acoustic, audio and RF instrumentation research and development. He has been instrumental in the design of sound level meters and analyzers, voltage and power amplifiers, preamplifiers, radio tuners, and other equipment.

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quency response and low distortion of the loudspeaker, the following characteristics should be considered as desirable. First, the impedance of the loudspeaker should vary no more than 2 to 1 over the operating frequency range and should approach rated impedance outside the operating frequency range. Also, the phase angle preferably should vary no more than 45°. All this should be done without sacrifice of efficiency. The reasons for this are simple. The amplifier most practical to design is one having a fixed damping factor in the range between 3 and 20. A variation in load impedance over a range of 2 to 1 results in only a relatively small variation of maximum available output power and a phase variation of 45° is readily accommodated.

A loudspeaker of such characteristics will probably be far in the future and for the foreseeable time amplifier designers will have to accommodate loudspeakers as they exist today. It is hoped this paper has pointed out some of the basic limitations of amplifiers which should be recognized by loudspeaker and system designers. Although all the previous discussion was based on the performance of an amplifier containing two 6L6 tubes, the results apply equally well to all feedback power amplifiers.

The Finer Structure of Magnetic Tape: Microscope Studies*

REUBEN M. CARES, M.D.†

Properties of tape coatings and bases are briefly reviewed. Utilizing tissue microtome techniques, sections of ¼" magnetic tape in three planes were prepared at 2 to 4 microns (80 to 160 micro-inches) thickness. Microscopy, under polarized and other lighting, and using up to 1500 magnification, revealed the internal structure and defects in the oxide coating. The shearing stress of the microtome technique tested coating adhesion, oxide shedding and coating integrity. Principal internal defects were pinholes, foreign bodies and oxide particle aggregates. Section profiles of coatings are related to surface features previously described. The behavior of polyester and acetate bases, in sectioning, was demonstrated. The lack of visible orientation of oxide particles at 1500 magnification, is presented. The possible relation of fine structure to recording performance is discussed.

1. INTRODUCTION

THE MAGNETIC properties of tape may be considered a function of its fine physical structure. Microscopy of tape may prove as fruitful as has been the study of grain structure in metallurgy, or the fine patterns of silver halides in photography.

It is our purpose to describe the finer microscopic nature of coatings and bases of ¼" tape. The surface characteristics and internal structure may be correlated with processing imperfections. Ultra-thin sections of tape made by a tissue microtome can disclose hitherto unobserved features. The shearing action of the microtome knife can serve as a micromethod for studying coating strength, adhesion to the base and oxide shedding.

TABLE I. Properties of Magnetic Iron Oxide (C. K. Williams Co., Easton, Pa.).

	Old Series		New Series	
"IRN" pigments	100	110	200	210
*Physical**—Type	ferroso-ferric	ferric	ferroso-ferric	ferric
Formula	Fe_3O_4	Fe_2O_3	Fe_3O_4	Fe_2O_3
Color	black	reddish-brown	black	brown
Magnetic (at 1000 oersteds)				
Coercive force, H_c (oersted)	300- 350	240- 300	300- 350	250- 350
Remanence, B_r (gauss)	1500-2200	1500-2200	1600-2200	1700-2200

* Do not necessarily conform to designations of other observers.

2. THE BACKGROUND: TAPE STRUCTURE cf FUNCTION

A few reports have been published on the finer structure of tape and its bearing on errors in performance. A brief survey of the literature may be pertinent.

2.1. Magnetic Iron Oxides

Table I lists the properties of older and more recent types of one major producer. The color of iron pigment is only roughly dependent on particle size. Surface conditions, the type of binder, and the caliper of the coating may also modify the shade of brown or black in the finished tape.

The several magnetic iron oxides, by electron microscopy, consist of acicular or rod-shaped crystals, averaging 0.7 × 0.1 micron.[1] For the purpose of calculating magnetic values, Osmond[2] considered the mean shape factor to be a prolate spheroid. This is not confirmed in the electron micrographs of Figure 1, at 18,000 power, of the oxides listed in Table I. The crystals appear rod-shaped, with jagged ends. Shadowing techniques in electron microscopy would be useful in delineating the third dimension. Precise three-dimensional effects have been successful with palladium shadowing at 100,000 × of viscose and acetate fibers.[3]

The influence of particle dimensions on remanence and coercive force needs further study. Smaller crystals (see Fig. 1) may permit a higher density of magnetic domains in the coating. This particle concentration has been termed the "packing factor" by Daniel and coworkers in their critical analysis of limitations in magnetic recording.[4]

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FIG. 1. Electron micrographs of magnetic iron oxide crystals, 18,000 magnification. A, B, C, D, are respectively, types IRN 100, 110, 200, 210 (see Table I). Courtesy of Mr. G. W. Cable, C. K. Williams Co.

2.2. Composition of Tape Coatings

Beside iron oxide, other coating ingredients affect the physical and magnetic characteristics.

Chemical Constitution:

Coating formulae are understandably secret. However, one formula that could be used for sound striping on motion picture film has been published,[5] as in Table II. A good formula entails the maximum concentration of oxide compatible with desired physical properties in the finished tape.

The non-ferrous film-forming materials aid proper oxide dispersion and provide the mechanical strength of the coating. Solvents of varying degrees of volatility facilitate fast drying and winding.

Physical Characteristics:

Dedell,[6] has described the properties of an ideal coating formula. These include good oxide dispersion, firm adherence to the base, minimum shedding of oxide particles and no physical deformation (cupping) of the dried tape. There should be minimum viscosity of the binder, as well as no softening of the film backing by binder solvents.

One might add other desirable features such as maximum smoothness, a low coefficient of friction, freedom from foreign bodies and lastly, an absence of adhesion between successive layers of wound tape.

TABLE II. Coating Formula for Sound Striping* (1953).

Solids	%	Solvents	%
Nitrocellulose	19.4	Butyl acetate	44
Maleic resin	4.8	Isopropyl alcohol	8
Castor oil	5.8	Methyl cellosolve acetate	8
†Fe_2O_3, gamma	70.0	Toluene	40

* Ingredients dispersed in a ball mill for 24-48 hours, then strained through 200 mesh silk bolting. Coating applied at 30-60 ft/min and dried under infrared lamps.
† IRN-110 Type, C. K. Williams Co.

2.3. The Nature of the Tape Backing

Most of the physical specifications of a good coating should be matched or exceeded by the base. Emphasis is placed on high tensile strength and stability in temperature and humidity fluctuations during recording or storage. Tape limpness or conformability to magnetic head configuration is desirable; it is particularly critical in recording at high frequencies. Limpness is maximized in the half-mil mylar tape.

The superior features of mylar polyester film compared to acetate bases, were analyzed by LeBel soon after its introduction.[7] Pertinent properties of mylar are included in Fig. 2 and Fig. 3. Radocy's recent method[8] is practical since it evaluates yield strength and elongation on three-foot lengths of tape. Such a segment approximates the free span of tape during transit between feed and take-up reels.

Microtome sectioning, as will be demonstrated, releases fine stresses in mylar and acetate bases, possibly arising during the reel-winding stage.

2.4. Tape Defects Related to Performance

External Imperfections:

A greater part of signal dropouts and noise pulses have been traced to defects seen under low-power microscopy. The nature and frequency of surface impurities have been described by at least two tape producers.[9,10] Removable errors are due to loosely attached particles of base or coating materials. Causes of fixed defects include coating discontinuities (pinholes), oxide flakes, slitter detritus, filter fibers and shreds of backing.

In a study of pinholes, Latham[11] found that they progressively enlarged on repeated playbacks. A loss in output occurred at all frequencies and was greatest below 300 cps. Similar recording errors, especially at high frequencies, have been traced to surface nodules by Schmidt.[12] He claimed that his micro-polishing technique improved recorded output as much as 2 db at high frequencies.

Other methods which attempt to offset errors in performance due to surface irregularities include buffing and rolling.

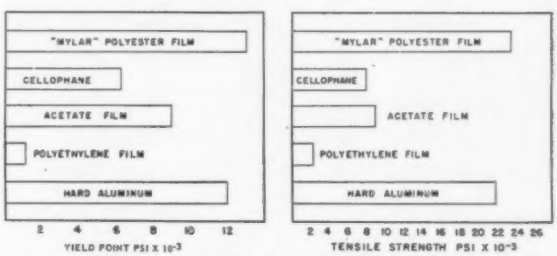

FIG. 2. Comparison of the yield point and tensile strength of mylar polyester film with other common thin films. Report TR-1, DuPont Co.

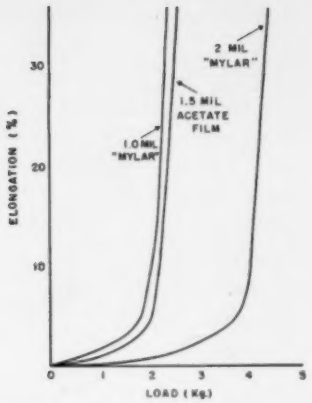

FIG. 3. Elongation of ¼" wide mylar polyester film tapes at various loadings. Report TR-1, DuPont Co.

Vis-à-vis gap lengths in magnetic heads, surface nodules may reach up to 3 mils across and project 0.15 mils.[13] Base materials, chiefly acetate, in one study, were responsible for about half of the tabulated defects.[10]

An opposite school of thought, including LeBel and his associates,[14] holds that any manipulation merely alters the shape of an irregularity without eliminating it. A peaked nodule may be transformed by buffing into a flattened droplet. This may introduce magnetic problems of a leading edge (or lip) and a trailing edge.

In the final analysis, prevention of surface defects is obviously worth more than any of the current remedies.

Internal Imperfections:

The alignment and dispersion of iron oxide particles inside the finished coating have hitherto not been demonstrated. The electron microscope technique is not adaptable for analyzing coatings since specimens must be far thinner than the conventional coating thicknesses of 0.30 to 0.65 mil. The morphology of films of liquid coating does not duplicate conditions in the finished tape.

Larger internal impurities are detectable on surface inspection. The character and frequency of internal coating defects may be best determined by thin cross-sections.

3. MATERIAL AND METHODS

3.1. Selection of Tape Samples

Reels or 10-foot samples of ¼" virgin tapes were supplied by four producers of both mylar and acetate types, with bases 1.5, 1.0 and 0.5 mils thick. Up to a dozen samples of ¾" lengths were selected at random. In relation to total footage on a 7" reel, the samplings were statistically too small for assaying the frequency of defects. We were concerned only with the varieties of imperfections.

It was assumed that the results obtained from ¼" tape would be similar to those obtained from tapes for computer, video, or sound-striping applications.

3.2. Methods

All materials of whole or sectioned tape were studied under the microscope with various lighting conditions.

Whole Tape Studies:

Several feet of tape were scanned with surface lighting under the microscope. Areas with surface defects were mounted, dry or in inert balsam, on slides. These were compared by reflected and transmitted light.

Microtome Sectioning of Tape:

Raw ¼" tape was embedded in histological paraffin and serial sections made at 2, 3 or 4 microns (0.08, 0.12 and 0.16 mil). Although 2 micron sections were too thin to define coating defects or inclusions, they were valuable for observing the disposition of oxide crystals. Sections at 4 microns caused no physical distortion of coating by the microtome knife. There was trouble in sectioning the silicone-impregnated coating of one manufacturer. The same coating, without silicone, cut like other brands.

It was important that sectioning should not alter the pattern of oxide particles existing in the completed tape. Uniform oxide dispersion, during manufacture, is at best difficult, as noted by Franck and Schmidt.[15] They felt that incomplete dispersion impairs high frequency response and sensitivity.

The thin paraffin "surround" of the 2 to 4 micron sections was dissolved by a few seconds' dip in xylol. The tape slices were then mounted with inert balsam under cover

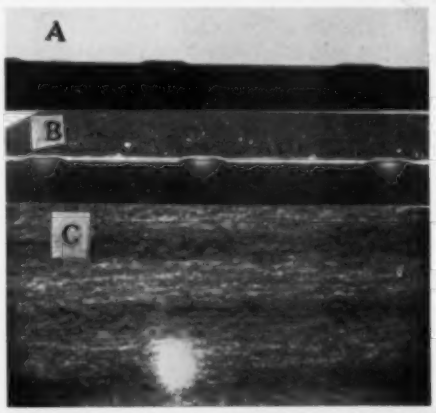

FIG. 4. Processing defects in magnetic tape. A—periodic edge defect, direct light, 100 ×. B—same specimen in darkfield light shows thinning of oxide coating. C—another sample by transmitted light shows striping of coating, and a pinhole, 100 ×.

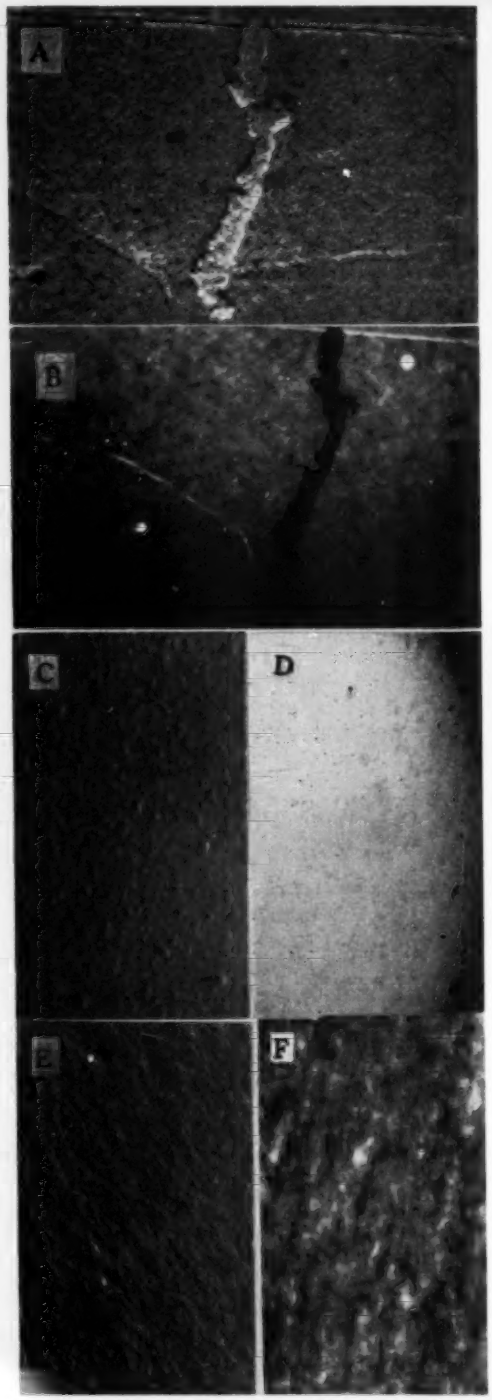

FIG. 5. Comparative external and internal coating structure. In A, the surface shows a long groove, a large embedded oxide clump, curved tracks and several pits. B—same field in transmitted light discloses pinholes. C and D—surface granulation of one make compared to its speckled oxide pattern by transmitted light. E and F are patterns of another make by similar lighting. All × 100.

glasses. One make of coating slightly disintegrated in the momentary contact with xylol. The untouched paraffin frame of this make still showed coating breakup similar to that in the sections exposed to xylol.

Familiarity with microtome artefacts in biological tissue was helpful in evaluating analogous changes in tape. The shearing action of the microtome knife, the effect of mounting processes on the integrity of the coating or base material and manipulation of the very delicate tape slivers—all these had to be taken into account. We are not sure whether the knife edge caused any displacement of oxide particles in the coating during the cutting phase.

Microtome sections were made in the three planes. Acetate stock gave little difficulty with the knife, behaving almost like gelatin. It was readily mounted without distortion. Mylar base was rubbery in behavior. It would tend to twist and curl during cutting, both at room temperature and after having been frozen with carbon dioxide snow.

To study the internal structure of the oxide coating, sections at 3 and 4 microns were made in the plane of the playing surface. We could occasionally obtain 2 to 4 consecutive frames at 0.16 mil (4 microns) thicknesses.

3.3. Lighting and Photography

Sections were examined by several microscope illumination methods—surface lighting, by transmitted light, in the darkfield and by polarized light. Findings in each modality tended to be confirmed by the others. At very high powers, the structural details of sectioned coatings required either darkfield or polarized light, in order to "burn through" the opaque pigment. Darkfield lighting was accomplished with a substage, variable focus condenser and central stops of different diameters in the plane of the iris diaphragm. We found that infrared lighting or color filters were not particularly useful. Polarized light clearly demonstrated the refractility of mylar. The rotation of the crossed polarizing lens was optimum between 50° and 80° for delineating internal defects. With the oil-immersion objective for powers to 1500 ×, oblique condenser lighting enhanced the resolution of oxide crystals.

For the high intensity of light required to penetrate the oxide pigment, Kohler illumination, a large field condenser, and a #2 photoflood bulb were used. Caution was exercised to avoid overheating of the raw or mounted whole tape or the sections. For this reason carbon arc lighting could not be used. Surface features were spotlighted with a ribbon-filament research illuminator. Color-corrected microscope lenses (apochromats) were used in connection with a Leica photomicrographic and copy apparatus.

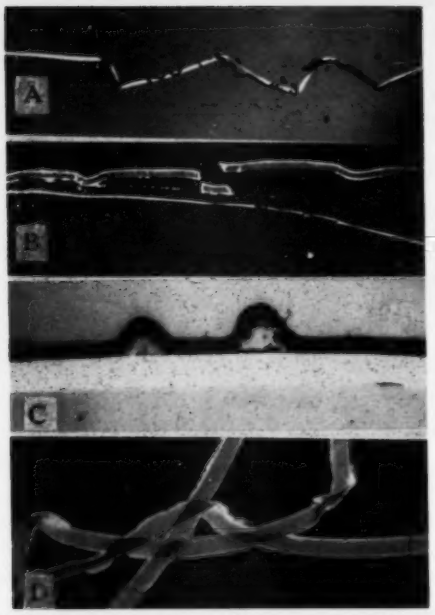

FIG. 6. Effects of microtome technique on coating integrity. A—extreme breakup of coating; polarized lighting, × 25. B—coating separation, 1 mil acetate tape, darkfield, × 75. C—microscopic coating blisters, 1 mil mylar tape, polarized light, × 210. D—same make of tape as in B, showing coating integrity in spite of excessive folding; darkfield, × 210.

4. MICROSCOPIC OBSERVATIONS

4.1. Features of Whole Tape

Processing Defects:

Since the commoner surface defects have already been reported, only a few additional findings will be described. One sample presented a periodic edge defect from the tape-slitting operation on the master roll (Fig. 4A). It may seem trivial, but in the darkfield (Fig. 4B), these areas showed thinning of the coating which could affect recording properties. Another processing defect is the longitudinal striping of the coating (Fig. 4C) disclosed by transmitted light. This may be due to guide rollers impressing the coating during the drying stage.

The most frequent defects—embedded oxide clumps, pinholes and scratches—are exemplified in Figure 5A. At 100 power, this surface view shows part of a long, straight scratch, a large clump of oxide, shallow hairline tracks and several pits. These features are readily seen by transmitted light. This shows that two of the pits correspond to pinholes (Fig. 5B).

Surface and Internal Patterns:

Each brand of tape and the several sub-types disclose "fingerprint" characteristics by surface and transmitted lighting. There was a fairly consistent pattern in one or more reels, of each company's tape. Two coating brands are illustrated in Figures 5C, D, E, and F. The nodular pattern of one make contrasts with the constant rippled or barred pattern of another.

4.2. Microtome Technique and Artefacts

Effects on Coating Integrity:

The shearing action of the microtome knife served as a microtest of mechanical strength. In general, coatings remained firmly bonded to the base. There were a few instances of coating separation seen among several hundred slides. Infrequently, one make of coating was brittle. It would detach and crumble, as in the extreme example seen in Fig. 6A.

Another coating formula peeled away rarely in many sections made (Fig. 6B), although specimens from other parts of the same reel resisted multiple folding (Fig. 6D). An odd shearing effect was infrequently manifested by microscopic blisters (Fig. 6C), caused by differing yield strengths of coating and base.

Shedding of Oxide:

A useful artefact was the shedding or powdering of oxide induced by sectioning at 2 to 4 microns. One of the four makes showed a consistently high resistance to coating disintegration, illustrated in the untouched paraffin "frame" (Fig. 7A). It appeared the same after removal of the embedding medium, prior to cover-slip mounting.

The kind of lighting used to reveal oxide shedding was critical. In Fig. 7B, a partly folded section, as viewed in polarized light, shows a minimum of free oxide. When the same section was observed in the darkfield, a much larger number of detached particles is revealed. Severe oxide shedding from microtome sectioning is seen in Fig. 7D. The degree of shedding was a fairly constant property of each coating formula.

Sectioning of Mylar:

The behavior of this base material to sectioning has been mentioned. The superior toughness demonstrated on whole tape by LeBel[7] is reflected in the microtome slivers. The elasticity or springiness of mylar sections contrasted with the flaccid, almost gelatinous reaction of acetate (Figures 7A, B, C). Mylar sections, even when cut well frozen, showed an occasional bizarre loop and helix pattern (Fig. 8B) or more frequently, a wavy arrangement (Fig. 8C). In polarized light its refractility yielded a beautiful play of colors which are seen as shadings in the black and white

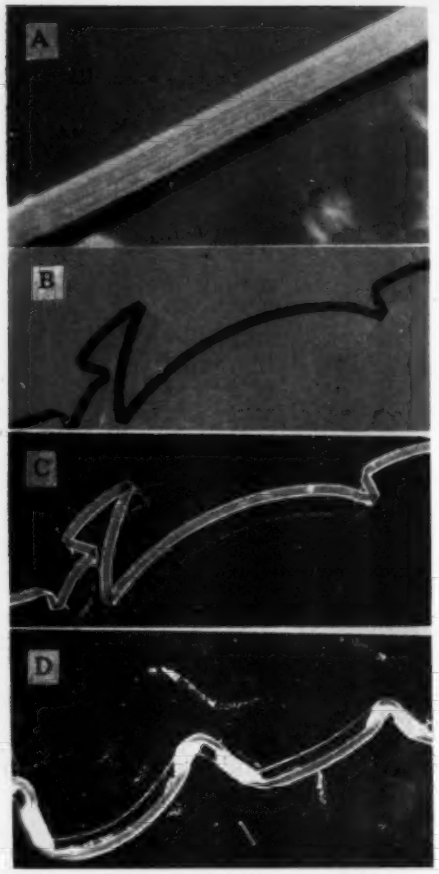

FIG. 7. Effect of 4 micron sectioning on shedding of oxide particles. A—one highly resistant 1 mil mylar tape type in untouched paraffin frame, showing paraffin crystals (clouds) at lower right. Polarized light, × 300. B—1.5 mil acetate tape in polarized light shows no free oxide particles, × 100. C—same view in darkfield reveals scattered particles and non-homogeneity of coating. D—extreme example of oxide shedding or powdering effect, in another brand, of ½ mil mylar tape, × 150.

photo of Fig. 8A. The twists and curls may indicate strains from reel winding or other processing that are released by the microtome sectioning. The uniformity in base caliper of the ½, 1 or 1½ mil bases was high. Defects were rare. Irregularities in thickness, foreign bodies and bubbles were not encountered. This is understandable in the statistically small sampling by 4 micron sections of a 6250 micron wide (¼") tape segment.

4.3. Cross-Sectional Features of Coatings

After excluding those sections with artefacts, the internal structure of coatings was considered. In Fig. 9 one can discern, in one small strip, the random non-ferrous inclusions, and the existence of oxide clumps (aggregates, agglutinates, floccules, agglomerates, nodules). For demonstrating minute non-ferrous inclusions, the darkfield (Fig. 9A) was less effective than polarized light (Fig. 9B). At × 650 magnification (Fig. 9C), these hidden foreign bodies can approximate in size the gap length of a magnetic head. They caused no disarray of surrounding oxide. In a number of tape sections, the darkfield made it possible to delineate the individual oxide clumps (Fig. 9D). These presented a cotton-wool or floccular pattern which would not be visible on surface inspection.

Coating smoothness is a highly desirable property. It has some relation to amplitude fluctuations in recording that are traceable to frictional forces.[4] Figure 10 shows two fairly representative sectional profiles of oxide coating. Even at 650 power, the smoothness of the coating-base interface is clearly contrasted with the irregularity of the playing surface of the coating. The contrast is also evident in Figures 7 and 9.

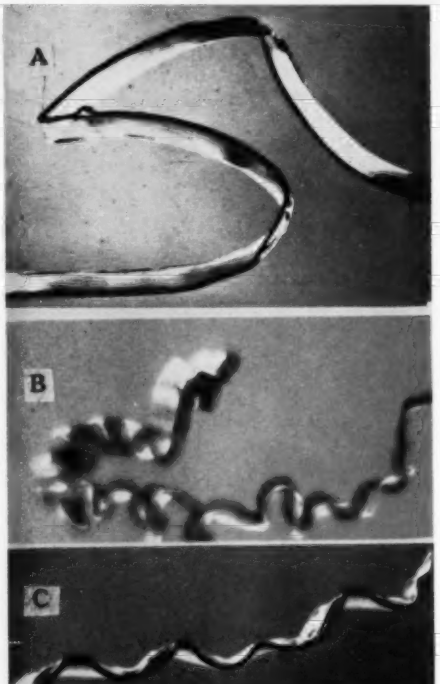

FIG. 8. Reaction of mylar polyester film to microtome shearing. A—1.5 mil base with extra thin coating (3M Co. experimental tape). The gray shading indicates the spectral refractility in polarized lighting, × 100. B—internal strains and elastic recoil of 4 micron slice. Base is seen edge-on of a 1 mil film; polarized light, × 100. C—1 mil tape cut at 3 microns. The coating is in focus. The inherent springiness has a rippled effect; polarized light, × 100.

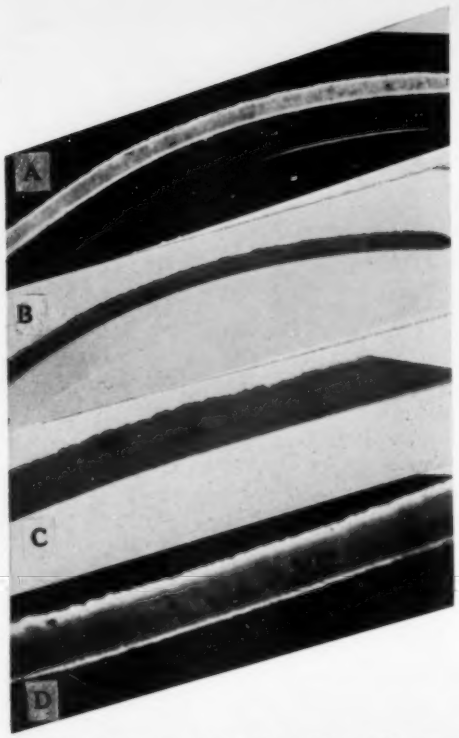

FIG. 9. Internal structure of oxide coatings with comparative lighting. A—1.5 mil acetate tape with non-ferrous inclusions, in darkfield. The base is seen edge-lighted, × 200. B—same specimen in polarized light shows improved delineation of the inclusions, × 170. C—higher power view of B; × 475. D—floccular or clumped disposition of oxide within a 0.55 mil coating elicited by darkfield, × 650.

4.4 Coating Sections in the Facial Plane

Facial sections through the 0.35-0.65 mil calipers were technically difficult, but we did obtain several shavings from each make. The darkfield lighting was strong enough to "burn through" the ordinarily opaque pigment. Figures 11A and 11B illustrate the internal texture of two different formulae. One reveals internal pinholes in a uniform field, the other displays scattered oxide clumps like "lumps in oatmeal."

To study the individual oxide crystals, sections should approach 1 micron. The question of visibility of discrete particles in the optical microscope has been understandably raised.[14] The optical microscope can visualize down to 0.2 micron. The tiny influenza bacillus averages 0.2 × 0.5 micron (comparable to the oxide crystal), and is regularly observed with oil-immersion objectives.

Figure 11C is part of a 4 micron facial slice that flaked or scaled spontaneously. This left an ultra-thin veil of coating as in the lower right area, in which the individual particles could be visualized. Figure 11D is the 1500 power view of this delicate flake. The basic structure of this patch comprises oxide aggregates or clumps. The intervening rarefied area appear one or a few crystals deep.

Finally, the thinned-out fringes of various facial sections (Figs. 11A, 11B) were examined at magnifications up to 1500 ×. One can see, in Fig. 12A, the fine rods and beads embedded in the transparent coating binder. Physical alignment or orientation of iron oxide crystals has been assumed to result from magnetizing the wet coat during manufacture. Definite alignment could not be identified in numerous sections, although some attempt was rarely observed as in the small centerfield of Fig. 12A.

In the minute fragments of coatings in the fringe areas (Fig. 12B), discrete oxide crystals, many with a fine capsule of plastic binder, were visible. They appear to be rod or fusiform in shape. The coarser fragments of the photo appeared to be composed of close-packed rods of iron oxide. At 1500 ×, they have the same morphology revealed in the electron micrographs at 18,000 magnification (Fig. 1).

5. DISCUSSION

5.1. Summary of Observations

The techniques utilized have demonstrated: (a) that internal structure of tape is partly related to surface texture; (b) all makes of coatings are generally well bonded to the base; (c) the degree of oxide shedding, in 4 micron sections, depends on the particular coating formula; (d) smoothness of the playing surface only approaches that of the base

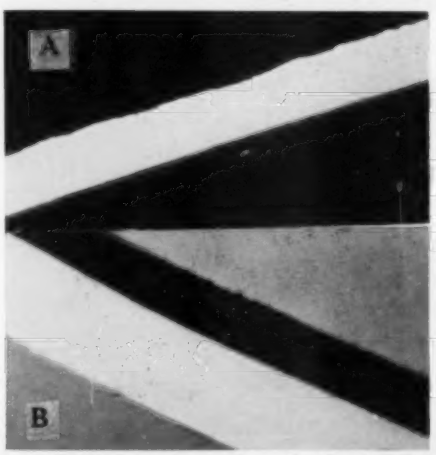

FIG. 10. Profile of cross-section of coating showing the free surface and interface with film base. A—1.5 mil acetate type; polarized light (90° rotation), × 650. Compare with its surface texture, Fig. 5E. B—1 mil mylar tape of another make; polarized light, × 650. Note extreme smoothness of interface, *cf* the surface, due to the glossy base.

films; (e) internal impurities are mainly pinholes and non-ferrous foreign bodies; (f) the magnetic oxide coating is composed of particle aggregates or clumps in varying degrees of dispersion and frequency, and (g) the magnetic field applied to the coating during the wet stage of processing does not cause directly visible particle alignment in the dried tape.

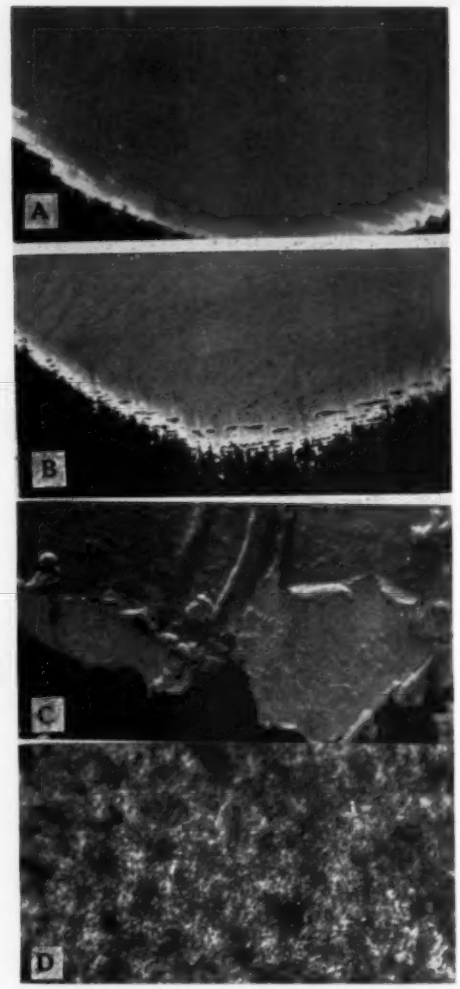

FIG. 11. Facial sections of coatings showing internal structure. A and B—are two types cut at 3 microns. Note pinholes in A and oxide agglutinates in B; darkfield, ×100. C—a 4 micron facial section that spontaneously flaked or "scaled." In the lower half, a 1 to 2 micron lamination of coating reveals the fine grainy texture, ×200. D—very high magnification of part of the scale in C, showing alternate condensation and rarefaction of oxide particles (clumping); darkfield, ×970.

Other microscopic features demonstrated have a minor bearing on magnetic performance, but corroborate prior surface studies. A few processing defects of whole tape arising in the slitting and winding stages have not been previously described.

5.2. Fine Structure Related to Performance

Westmijze pointed out that magnetized tape had more noise than virgin tape.[16] He reasoned that since oxide particles were clustered in the coating with interstitial rarefaction, each magnetized cluster acts as a dipole with resulting outward lines of force. A parallel approach to the theoretical influence of oxide particle size and disposition on coercivity was made by Osmond.[2]

As our studies indicate, a consistently homogenized coating has not been achieved. However, the industry has greatly reduced the incidence of impurities and defects. Oxide coating in the present state of the art, may be analogous to the graininess of photographic silver emulsions existing some decades ago. These did not match the potential resolving power of optical lenses. Improvements in oxide homogeneity may possibly be obtained by such techniques as supersonic vibrations on the liquid stage, the adoption of extremely slow-drying vehicles, freeze-vacuum drying (lyophil process), etc.

Some dropouts have been traced by Hard[17] and Radocy[10] to non-ferrous coating inclusions. Hard believes that during magnetic orientation of the wet coating, small foreign bodies cause a disproportionately large disturbance in the magnetic flux. In checking our sections with internal non-ferrous bodies, we could not detect any consistent alteration in the arrangement of oxide particles surrounding such inclusions (see Fig. 9).

Several other questions arise. Excluding deviations in coating calipers, how closely do variations in particle density (the packing factor of Daniel, et al.), affect amplitude stability? Secondly, how do oxide clumps that are larger than gap lengths of magnetic heads affect high frequency noise or the limit of treble response? Also, what proportion of magnetic variations stem only from internal foreign bodies and ferrous discontinuities (pinholes)? Lastly, what improvement in performance would be accomplished if the coating surface matched the smoothness of current base films?

To answer these problems, we agree with LeBel, that a highly refined series of performance measurements is required. One approach would entail probing of small areas of coating with magnetic heads having contact surfaces the area of a pinhead, or smaller. The high-speed rotating head utilized by Latham[18] in oscilloscopic studies of pulses in recorded tape, may find use in "electrically magnifying" high frequency data. The electronic parameters should be as sensitive as is high-power microscopy in resolving the finer structure of magnetic tape.

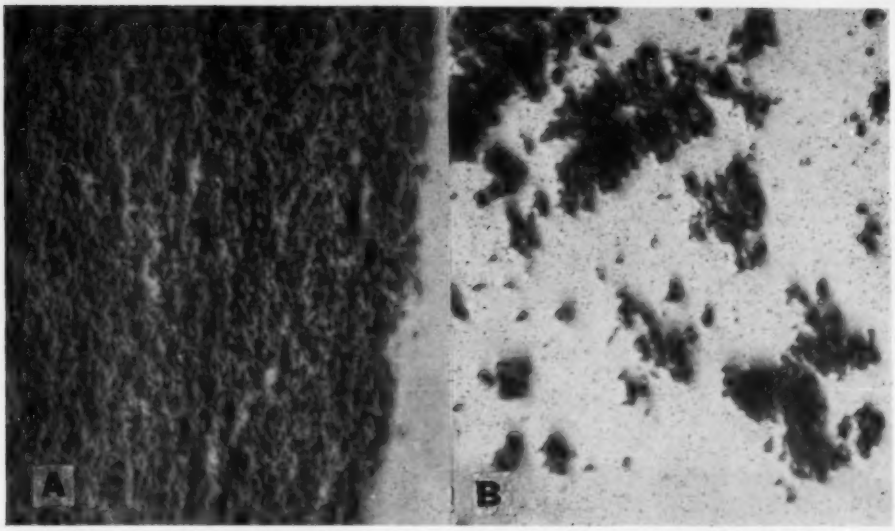

FIG. 12. Oxide particles in an ultra-fine layer of magnetized coating, estimated as 1 micron (.04 mil) thin. Compare with Fig. 1. A—the rod-like shapes are in random array, except for slight alignment in center field; the coating binder is translucent, ×1500. B—extreme frayed edge of a facial section showing individual particles; ×1500.

6. ACKNOWLEDGEMENTS

Tape materials were supplied by the research departments of Audio Devices, Inc., ORRadio Industries, Reeves Soundcraft Company and the Minnesota Mining and Manufacturing Company. The keen interest and constructive criticism of Mr. C. J. LeBel (Audio Devices) and Mr. H. G. Hard (ORRadio) are deeply appreciated.

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In the audio field, Dr. Cares is the author of "A Semicircular Exponential Horn" and "Interdependence of Design and Audio Effects in Tape Recording." He has constructed seven successive high fidelity music systems for the home since 1938. By virtue of 30 years' study of microscopic and microtome techniques, and because of his wide experience in high-power photomicrography, Dr. Cares has become an authority in the minute study of the structure of tape coatings and bases.

A New Approach to the High Performance Turntable Problem*

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During the past twenty years, electrical phonograph drive systems have remained practically unchanged, and many of their basic shortcomings which give rise to wow, flutter, and rumble still persist.

One solution to some of these shortcomings is described in the form of an electronic drive turntable, consisting of a variable frequency oscillator and a power amplifier driving a hysteresis-synchronous motor capable of working over a wide frequency and speed range. Such a drive system makes speed changing extremely simple since it reduces the number of necessary mechanical linkages in the drive system and has certain other advantages over mechanical transmissions used in turntables.

TURNTABLE DRIVE METHODS

PLANNING a new turntable design involved a thorough investigation of known transmission and speed-change methods. The following systems were investigated:

1. *Rubber puck drive.* The good features of a rubber puck drive include low cost and ease in changing speeds. The disadvantages include high rumble due to the relatively tight (lateral) coupling between the motor shaft and the turntable, necessary from the fact that it is impractical to use rubber idlers with a durometer reading of less than 40.

Rubber idlers often develop flat spots and/or change their concentricity due to (1) nonhomogeneous rubber molding (See Fig. 1), (2) random curing of the rubber caused by heat during the grinding operation, and (3) plastic deformation caused by prolonged pressure applied to a single spot (such as leaving the idler engaged with the motor turned off).

2. *Gear drives.* Gear drives could be successfully used if price were no object. In order to get flutter- and wow-free operation, very precise gears are necessary. The gear train and motor assembly must be isolated from the turntable to obtain a low enough rumble figure. The aforementioned properties make gear drives usable only in the most expensive professional equipment.

3. *Combination belt and rubber puck drive.* This system is superior to the rubber puck drive because it provides better isolation between the motor and turntable. If some form of automatic disengaging device is used between the motor and the pulley, this system is quite satisfactory.

4. *Belt drives.* Belt drives have long been used in many professional recording lathes. They have proved themselves superior to other methods of power transmission from motor to turntable. Their principal drawback, however, lies in the fact that there seems to be no practical way of selecting speeds easily unless the inconvenience of actually changing drive pulleys or shifting belts on step pulleys could possibly be considered a practical solution.

Two configurations in basic belt drives were considered. First of these was the single-belt drive, which is the simplest to build. Investigation revealed, nevertheless, that the immense speed ratio of 1:54 (33⅓ to 1800 rpm) does not give satisfactory service because of the very small contact area between the motor pulley and the belt unless a very high belt tension is used. A tight belt forms an easy path for transmission of vibrations to the turntable. Such a belt will also load the bearings unnecessarily, thereby causing flutter and premature wear.

The second configuration, which is the one finally chosen for this application, involved an idler pulley and two belts (Fig. 2). The final reduction distribution selected was 1:4 on motor to idler, and 1:13.5 on idler to turntable. This system has little enough slippage to give over 100 oz-in. stall torque which is more than sufficient to overcome bearing friction and drag produced by certain pickups. This system also shows very high rumble isolation.

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† Chief Engineer.

‡ Audio Engineer.

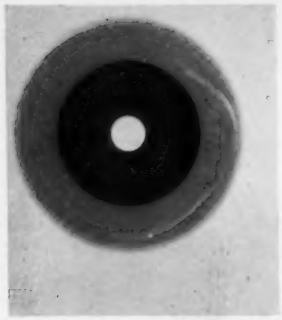

FIG. 1. X-ray picture showing nonhomogeneous rubber molding.

A NEW APPROACH

Most interesting was the inescapable conclusion that a new approach was necessary in solving the transmission problem of the phonograph turntable. It was apparent that the best solution would be to use a double-belt drive with a variable speed motor. Unfortunately it is not possible to build motors which have the exact multiple-speed ratios necessary for operating a turntable, such ratios being 1:1, 1:2, 1:2.7, and 1:4.7. One could possibly envision the design of such motors, but they would require hundreds of poles and would very likely measure several feet in diameter. (Motors of this type, which are intended for 33⅓ and 78 rpm operation, have been made by Lyrec, in Denmark). The only other approach was to find a synchronous motor capable of working over a relatively wide frequency range, and to generate locally the power with which to drive the synchronous motor at the required speeds of 900, 1800, 2430, and 4226 rpm. Such a synchronous motor was found, and the problem was then reduced to the design of a matching oscillator-amplifier to drive it.

Another important advantage is the possibility of controlling torque by selecting the optimum operating voltage for each turntable speed. Referring to Fig. 3, it will be seen that a conventional drive, owing to the mechanics of the speed reduction system, delivers the least torque at the highest operating speed. Or, to put it another way, this is a constant power system, at least theoretically. In actual practice, the losses are higher at high turntable speeds, so that both torque and power delivered are lowest at 78 rpm.

With electronic drive, however, the voltage delivered to the motor is made highest for 78 rpm, and therefore the torque, and consequently the acceleration, is greatest at higher speeds, and full speed is reached more quickly. One great incidental advantage ensuing is that a motor of 30-watt rating delivers performance superior to that of the customary 70-90-watt motor of other designs.

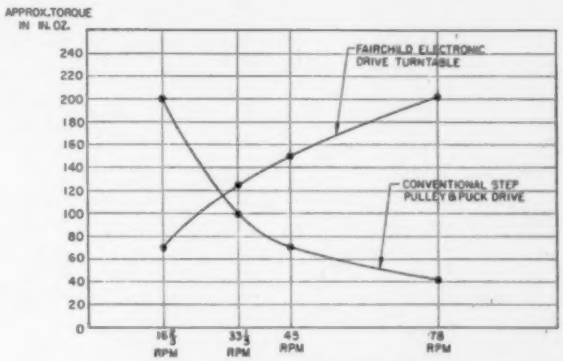

FIG. 3. Starting torque of turntables.

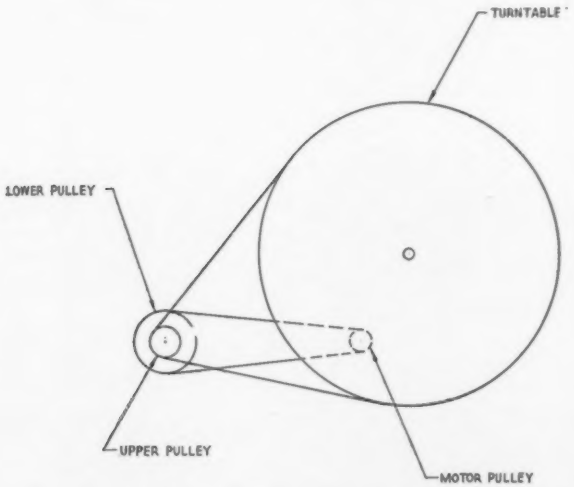

FIG. 2. The two-belt system between the motor pulley and the turntable.

DESIGN AND DESCRIPTION OF THE MECHANICAL ASSEMBLY

In order to serve its purpose under all conditions, the turntable must fulfill certain requirements, including the following:

1. A high moment of inertia to reduce incremental variations in speed (wow and flutter), accompanied by relatively low weight.

2. Precise physical dimensions and high dimensional stability with respect to both time and temperature, and an absence of sharp resonances in the audible spectrum (ringing).

To fulfill these requirements, the turntable was designed as an aluminum casting with five webs (Fig. 4). The outer segments of these webs support the added mass of the material "Densite" which is concentrated along the rim of the

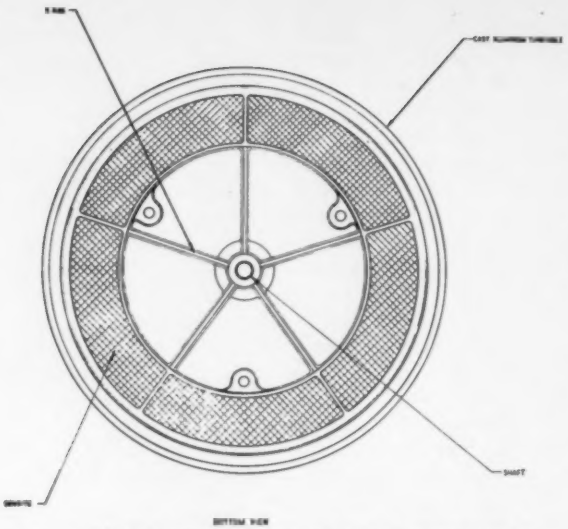

FIG. 4. Webbed aluminum turntable with "Densite" filling.

turntable. The entire turntable is machined in a single setting so as to minimize eccentricities, the Densite serving a double purpose by adding to the moment of inertia and by damping out audible ringing.

The main bearing of this turntable is equally important and must have very uniform friction. In the unit described, this bearing is made of a tin-base Babbitt alloy, rifle-drilled. The weight of the turntable rests on a steel ball which is supported by a nylon disc and rotates with the shaft. The entire bearing is enclosed within a heavy, rigid, cast-zinc bearing well, which is fastened to both top and bottom of the chassis thereby giving the structure strength and resistance against vibrations set up by the moving parts. No serious resonances have been measured in the bands of vibration frequencies present.

The motor is an accurately balanced hysteresis-synchronous type with good starting torque, the outer rotor serving the double purpose of providing high moment of inertia and good ventilation. A can around the motor, with proper cutouts to provide for constant forced-air cooling of the amplifier, also attenuates audible noise from the motor.

The motor rests in a cradle which in turn is suspended by flexible mounts. These mounts are tilted 45° to isolate equally well the horizontal and vertical vibrations. The cradle of the motor is reinforced so as to add stiffness, and extra weight is added, placed so that its center of gravity is close to the mass center of the driving motor pulley.

Two belts are used to drive the turntable by the motor *via* an idler pulley. As belts can be manufactured in almost any size and with controlled properties, this kind of drive was found to be superior to other methods.

Referring to Fig. 5, we see the upper belt, which is mostly resistive and couples the turntable to the idler pulley. The lower belt is compliant and couples the idler pulley to the motor. The pulley assembly is mounted in an elastic suspension between two neoprene washers and isolates belt and bearing vibration from the chassis, and in addition tends to compensate for variations in belt length with temperature, humidity, and time. The drive is basically a system of low pass filters (Fig. 5).

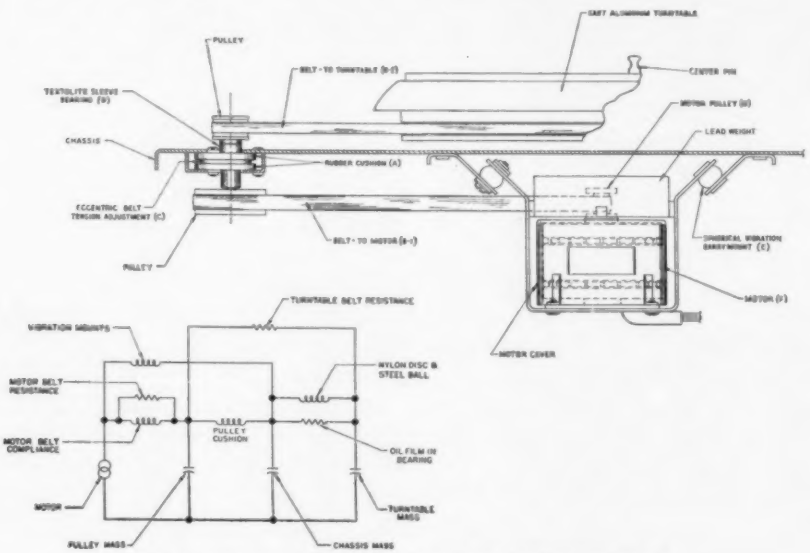

FIG. 5. Mechanical driving system and its electrical equivalent.

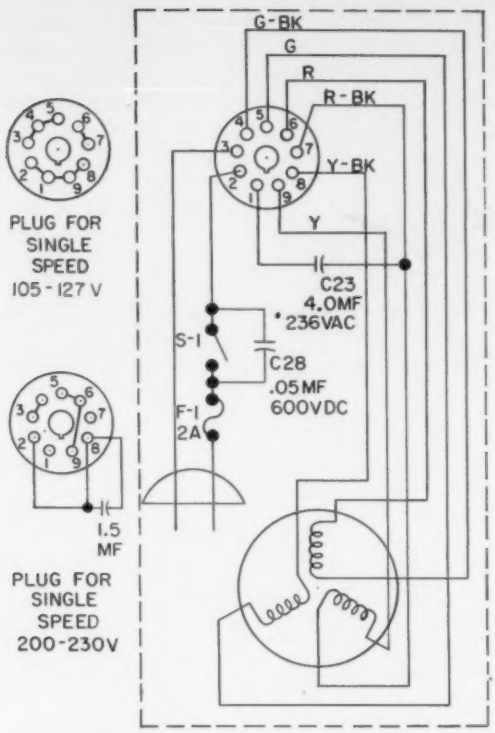

FIG. 6. Schematic for single speed unit.

The pulley assembly is further adjustable by means of an eccentric mount so as to accommodate a wider range of belt lengths. The bearing of the intermediate pulley is made of graphite-filled Textolite which has low coefficient of friction and good wear properties.

The electrical components of the mechanical assembly are quite conventional (Fig. 6). All connections appear on a 9-pin socket to permit easy conversion from electronic frequency converter to power-line operation. The motor is connected in delta for 105-127 volts, and in "Y" for 200-230-volt operation.

The mechanical assembly is a complete, self-contained, single-speed turntable which is known commercially as the Fairchild Model 412-1. This is a rather novel feature, since people who are interested in LP reproduction only, can purchase this unit as a single-speed turntable. It is very simple at any later date to convert this mechanical assembly into a four-speed unit by the mere addition of the electronic frequency converter unit.

DESIGN AND DESCRIPTION OF THE ELECTRONIC DRIVE UNIT

The generator chassis contains a stabilized oscillator; one push-pull RC-coupled voltage amplifier stage; one cathode-follower driver stage; and an output stage capable, with a reasonable margin, of delivering enough power to synchronize the motor at its highest speed of 4226 rpm. The necessary power varies with the value of the motor-running capacitor and the frequency.

The oscillator is a conventional Wien-bridge circuit, the four speeds being selected by switching capacitors with *S-2A* and *S-2B*. Four vernier controls are provided for fine adjustment of the four oscillator frequencies—30, 60, 81, and 141 cps. The condensers are silvered mica with a temperature coefficient of 0 to +100 ppm/°C. The precision resistors used have a temperature coefficient of about –200 ppm/°C, as resistors with smaller temperature coefficients were not available in the proper values. The vernier controls have a higher temperature coefficient, but as their ohmic values are only one-eighth that of the precision resistors, the frequency drift caused will be comparatively small. The worst condition is about –200 ppm/°C, the best –100 ppm/°C, or, in per cent, +.02 and +.01%/°C of turntable speed, respectively. The negative change in RC oscillator frequency-determining components will, of course, increase the frequency, hence the positive change in turntable speed.

Since this oscillator is a high-impedance circuit, it must be well shielded. The entire oscillator section, including the vernier controls and the switch, is fully enclosed in a grounded box which thereby prevents any stray capacitance of nearby components and wiring from synchronizing the oscillator to the powerline frequency or any multiple thereof.

The oscillator tube is a 12BH7 (*V1A* and *V1B*) with negative feedback from the plate of the second to the cathode of the first half of the tube. An incandescent lamp in the cathode of the first half keeps the amplitude nearly constant. An 0A2 VR-tube (*V6*) is used to minimize the influence of varying plate voltages and also to serve as an additional filter section. The second tube in the oscillator circuit (*V1B*) serves a dual purpose. It provides the necessary phase inversion for proper operation of the Wien-bridge oscillator and also acts as a phase splitter to feed the push-pull voltage amplifier stage which follows.

The push-pull voltage from this phase splitter is fed to a balanced voltage amplifier stage, employing a 12AX7 tube (*V2A* and *V2B*). The voltage amplifier feeds a 12BH7 cathode-follower driver (*V3A* and *V3B*) which in turn drives the output stage, delivering about 3 watts to the grids.

As reduction of the heat dissipated in this amplifier is an important factor in the design, maximum efficiency is more important than low distortion. The ideal output stage for this application would have been a push-pull class B_2 output stage, utilizing high-mu triodes. Unfortunately tubes in the given size and plate-dissipation ratings were not readily available. As the best possible substitute, two 25BQ6's (*V4* and *V5*) were used. These tetrodes were connected as high mu triodes by tying g_1 and g_2 together. This is the most efficient output configuration, since during the positive input cycle a very high I_b maximum is obtained with a very

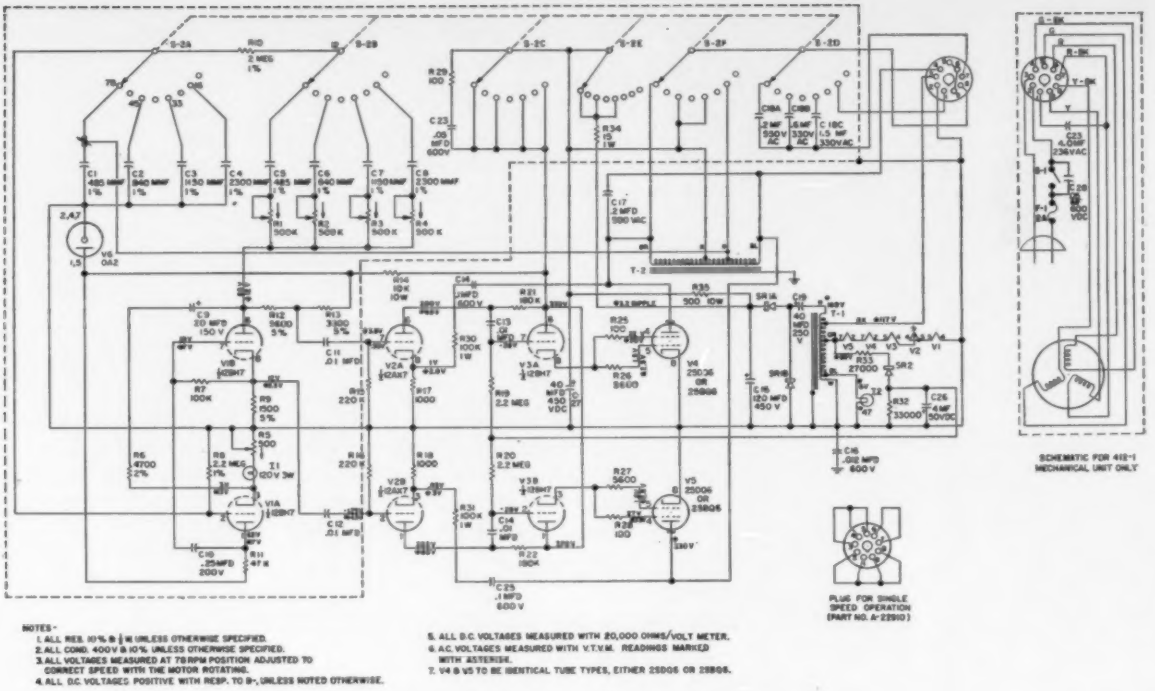

FIG. 7. Schematic diagram of electronic drive generator.

low E_b, the limit being $E_b\,(\min) = E_{(g_1+g_2)}\,(\max)$. This circuit also permits omission of heat-dissipating cathode resistors. A rather high output of about 30 watts is obtainable with a low plate voltage of slightly over 300 volts. The driver stage and therefore also the output stage is biased to cut off for highest running efficiency and minimum heat dissipation in standby position.

To gain maximum copper efficiency, an autotransformer is used to couple the tubes to the motor, permitting a small dc current to flow through the motor. This does not, however, seem to impair its operation in any way.

A feedback circuit is connected from the plates of the output tubes to the cathodes of the voltage-amplifier stage, resulting in about 10 db feedback. This feedback tends to reduce the effects of line-voltage variations. Without feedback, a 10% line-voltage variation produces a 12% change in the voltage fed to the motor. With the added feedback, a 10% line-voltage variation changes the output voltage by less than 4%. This accounts partially for the relative immunity which this unit shows to line-voltage fluctuations.

The schematic, Fig. 7, shows one switching arrangement. Section *S–2C* switches the B+ to the driver stage only. In neutral positions no B+ voltage is supplied to the driver plates, hence no positive bias appears at the output grids, and the tubes are cut off.

There are basically two sources of noise which would ordinarily produce clicks in associated equipment. First, a hysteresis-synchronous motor acts as a generator as long as the poles created by the rotating field in the hysteresis ring exist. Completely disconnecting the motor-running condenser would give rise to a voltage peak audible as a click in associated equipment. Use of a shorting-type switch eliminates noise from this source.

The second potential source of noise is the switch section *S–2C*, switching the plate supply voltage. A noise suppressor (*R–29* and *C–23*) eliminates clicks from this source.

S–2D shifts between the different taps of the output autotransformer (T–2) as the motor impedance changes with frequency. This arrangement causes less electrical power to be fed to the motor at lower speeds so that proper working temperatures are maintained. *S–2E* switches the motor-running capacitors which are chosen for optimum torque and minimum vibration of the motor. The vibration is measured with a Badmaieff FM Disc Cutterhead Calibrator and an oscilloscope, although any other proximity pickup could be used. For best power transfer at the highest speed, the output impedance of tubes should match the motor Y-connection.

The power supply is also designed for maximum efficiency. An autotransformer (*T–1*) supplies 150 volts ac to a selenium voltage-doubler (*SR–1A* and *SR–1B*), 82 volts to a series heater string, and 6 volts to the pilot light. By this

means, heat-dissipating series resistors in the filament circuit are eliminated and sufficient plate voltage is obtained by means of the voltage-doubler.

The winding resistance in this autotransformer is sufficiently large to limit peak-rectified current to 2.5 amp, a value low enough to protect the selenium rectifier used. The 4 mf motor-running capacitor (*C–23*), which is used in the 412-1 Single-Speed Unit at 33⅓ rpm (delta connection), is used in the Four-Speed Unit as a capacitor at 16⅔ rpm with the motor in Y-connection.

CONCLUSION

This paper has shown a new approach in designing high-quality phono turntables. As in any other field, continuous progress will keep the industry in motion. Just as hydraulic torque-converters have replaced conventional transmissions in automobiles and gas turbines are replacing piston engines in airplanes, electronics may well replace conventional drives in turntables, tape recorders, and all other devices requiring uniform motion and the ultimate in control.

THE AUTHORS

Mr. Narma was educated in Estonia, where he studied electromechanical engineering. He has done intensive work on electronic film recording, and made a study on biasless tape recording while working for Rangertone, Inc. He is also interested in the development of tape and disc recording amplifiers. Mr. Narma is now chief engineer at Fairchild Recording Equipment Company.

Mr. Skov received his master of science degree in electrical engineering from the Technical University of Denmark. He worked for five years as a research and development engineer at Linnet & Laursen Incorporated, Copenhagen. He came to the United States in 1956, to work with his present company as audio engineer. Mr. Skov is a member of the Danish Acoustical Society.

Application of Negative Impedance Amplifiers to Loudspeaker Systems*

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Successful application of negative damping factors to loudspeakers is not so difficult a task as one would infer from the literature of recent years. Foremost in importance are the cancellation of voice-coil inductance as well as resistance, equalization for low-frequency radiation characteristics; and utilization of infinite baffle rather than a reflex or horn type. When satisfactory attention is granted these factors, substantial improvement in loudspeaker performance is almost certain. In a typical application of a negative impedance amplifier, resonant hangover is eliminated, the nonlinear distortion halved, and the low-frequency response leveled and extended about an octave.

INTRODUCTION

IT IS well known that the output impedance of an amplifier affects the performance of a moving-coil loudspeaker to which it is connected. However, comparatively little attention has been given to the behavior of loudspeakers when driven by negative impedance sources.

GENERAL EFFECTS OF OUTPUT IMPEDANCE

The performance of a loudspeaker in the frequency range where cone breakup occurs is more or less beyond the control of the driving amplifier. At frequencies below about 1000 cps, however, the sound pressure is directly determined by the motion of the voice-coil. Just as the mechanical load on an electric motor is reflected as a change in electrical load on the power line, so are the mechanical characteristics of a loudspeaker reflected into the electrical circuit. Thus it should be (and is) possible to utilize the changes in electrical impedance to control the electrical signal to compensate for undesirable changes in mechanical impedance.

Referring all of the low-frequency mechanical and acoustical characteristics of the loudspeaker to the electrical circuit results in the equivalent circuit of Fig. 1. Here it is seen that the cone suspension and box compliance combine to form a single inductance. Since the cone suspension is non-linear, this non-linearity is reflected in the inductance. This inductance is in parallel with the capacitance which represents the reflected mass of the cone. These elements resonate to give the familiar rise of impedance at resonance. If it were possible to connect a very low impedance generator across these elements, the cone resonance would be eliminated. Furthermore, since the compliance is short-circuited, the non-linear distortion is reduced. Unfortunately, the voice-coil impedance isolates these components from the speaker terminals, so that to achieve these effects we must effectively eliminate the voice-coil impedance. An amplifier whose output is negative can accomplish just that. Whether or not the results are as desired is dependent upon factors which, to be identified, require more than a cursory examination of the equivalent circuit.

LOW-FREQUENCY RESPONSE

The basic factor in the low-frequency response of a loudspeaker is the radiation resistance of the cone, which increases with the square of the frequency, that is, at a rate of 12 db/octave. If the velocity of the cone were independent of frequency, as it is when it is heavily damped, it can be shown that the sound pressure in front of the speaker will rise 6 db/octave with increasing frequency. In the ordinary loudspeaker uniform low-frequency response is obtained by making the cone resonant at a low frequency. Above the resonant frequency, the cone is mass-controlled and its velocity falls 6 db/octave with increasing frequency, compensating for the rising radiation resistance of the cone, and resulting in uniform sound pressure output. Fig. 2 illustrates the influence of the radiation resistance on the response of a loudspeaker.

If the loudspeaker cone is heavily damped by any means, its velocity will tend to become independent of frequency and the low-frequency response will fall off with a 6 db/octave

* Received October 7, 1957. Delivered before the Ninth Annual Convention of the Audio Engineering Society, October 12, 1957.

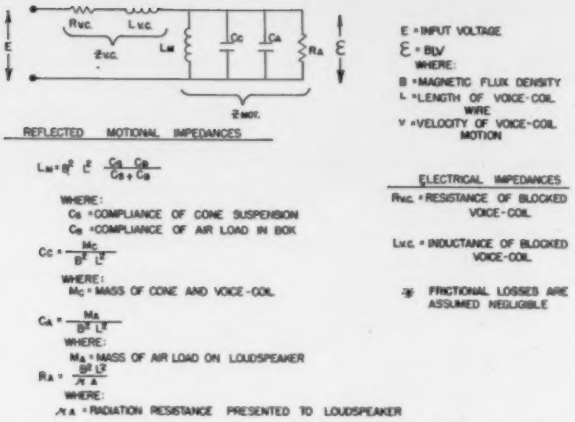

FIG. 1. Common equivalent circuit for direct radiator moving-coil loudspeaker.

slope. This must be compensated for by equalization in the amplifier. If the damping is accomplished by means of acoustical or mechanical damping, the damping constitutes a power sink and the amplifier must deliver substantially greater power output at low frequencies. If the damping is accomplished by electrical means, then the amplifier need not supply added power down to the resonant frequency of the loudspeaker. If the compensation is carried beyond the speaker resonance, then additional power will be required. Curves 1 and 2 of Fig. 3 indicate the output requirements of a negative impedance amplifier at low frequencies.

HIGH FREQUENCIES

In the high-frequency range, the voice-coil serves mainly to excite the cone and exercises little control over its vibration. Therefore there is little that can be done electrically (other than simple equalization) to compensate for deficiencies in the high-frequency performance.

Unless the negative impedance amplifier is properly designed for the speaker with which it is used, the interaction of the speaker and amplifier may seriously upset the overall frequency response curve.

If the amplifier is designed to exhibit only a negative output resistance sufficient to nearly cancel the voice-coil resistance, the voice-coil inductance will remain in series with the parallel resonant circuit which constitutes the motional impedance of the cone. This voice-coil inductance will resonant with the capacitance of the motional impedance at a frequency of a few hundred cps. The resonance can be quite pronounced, since the resistance in the circuit is nearly cancelled out.

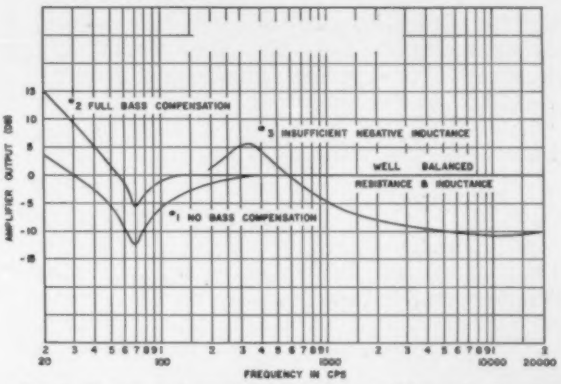

FIG. 3. Response of negative impedance amplifier at loudspeaker terminals.

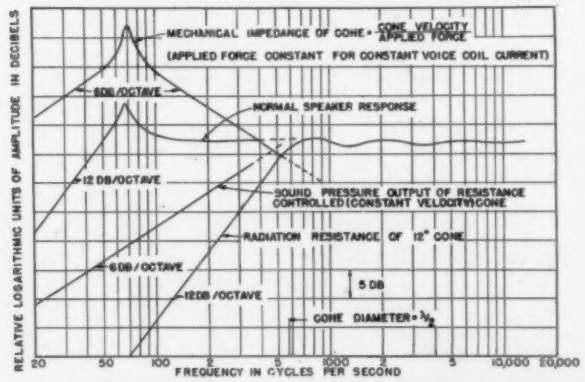
RELATIVE LOGARITHMIC UNITS OF AMPLITUDE IN DECIBELS
MECHANICAL IMPEDANCE OF CONE = CONE VELOCITY / APPLIED FORCE
(APPLIED FORCE CONSTANT FOR CONSTANT VOICE COIL CURRENT)
6DB/OCTAVE
NORMAL SPEAKER RESPONSE
12 DB/OCTAVE
SOUND PRESSURE OUTPUT OF RESISTANCE CONTROLLED (CONSTANT VELOCITY) CONE
RADIATION RESISTANCE OF 12" CONE
6DB/OCTAVE
5 DB
12DB/OCTAVE
CONE DIAMETER = 1/2
20 50 100 200 500 1000 2000 5000 10,000 20,000
FREQUENCY IN CYCLES PER SECOND

FIG. 2. Impedance and radiation characteristics of a hypothetical 12" loudspeaker cone in an infinite flat baffle.

It is necessary, then, that the inductance, as well as the resistance, of the voice-coil be cancelled out. This is simple enough in principle. Accomplishing this is another matter, since the voice-coil is surrounded by the iron magnet structure with its hysteresis and eddy-current losses. This results in a rather impure inductance, whose impedance may not rise at 6 db/octave.

If the actual impedance characteristic of the speaker is not matched by the negative output impedance of the amplifier, the overall high frequency response characteristic may resemble curve 3 of Fig. 3.

These effects become more pronounced as the impedance of the voice-coil is more nearly cancelled out.

A neglect of the voice-coil inductance may account for some of the disappointment which has attended the use of negative output impedance amplifiers. Certainly, the use of a large negative resistance alone will degrade the performance of the speaker rather than improve it.

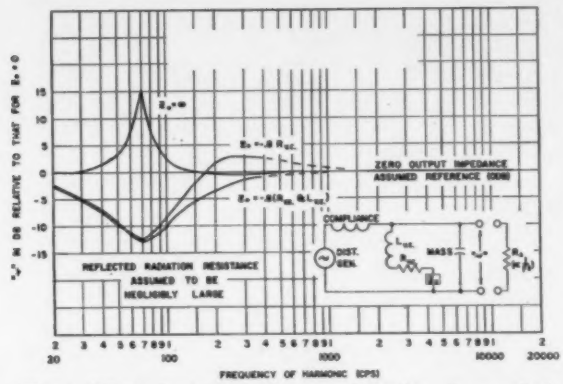

FIG. 4. Effect of output impedance on distortion of cone velocity relative to distortion for zero output impedance.

TRANSIENT RESPONSE

In general the discussion on frequency response is applicable to transient response problems. If the voice-coil impedance is shorted out, the resonant mechanical circuits are effectively shorted out. Here too it is important that the voice-coil inductance be substantially cancelled since its Q is increased if only the voice-coil resistance is reduced, and its resonance with the moving mass can occur at a frequency only slightly higher than the original speaker resonance. This new resonance may be more offensive than the natural cone resonance which is suppressed.

DISTORTION

There are two major sources of distortion in a loudspeaker, the non-linear distribution of the air-gap flux and the non-linearity of the cone suspension. Of these, the cone suspension is the more important. When the electrical impedance of the voice-coil is cancelled out by the amplifier, the cone is driven by a very low reflected mechanical impedance and the distortion is greatly reduced.

If the voice-coil resistance alone is cancelled out, we have seen that the cone will resonate at some point above the normal resonant frequency. If the cone is driven at some sub-harmonic of this new resonance, any non-linearity of the cone will be emphasized, resulting in an actual increase of distortion over what it would have been if the output impedance were zero. This is illustrated in Fig. 4, for a hypothetical speaker. These emphasized distortion components lie at a comparatively high frequency, where the ear is more sensitive than in the region of the cone resonance and where the radiation efficiency of the speaker is greater.

If the inductance is suitably cancelled, the loudspeaker distortion is reduced over a wide range of frequencies.

A NEGATIVE IMPEDANCE SYSTEM

A practical negative output impedance amplifier circuit is shown in Fig. 5. Negative voltage and positive current feedback are mixed at the output and fed through a common feedback loop. This arrangement is very stable and provides effective control of the output impedance to the extremes of the audio spectrum. Bass boost to compensate for the low frequency radiation characteristics is accomplished in the feedback loop without reducing the efficiency of the negative impedance circuit in the frequency range of interest. Internal positive and negative feedback are employed to produce a basic amplifier of high gain and very low distortion.[1] The .02 μf capacitor "C" produces the negative inductance and also adds treble boost to compensate for the approximation of the correct inductance.

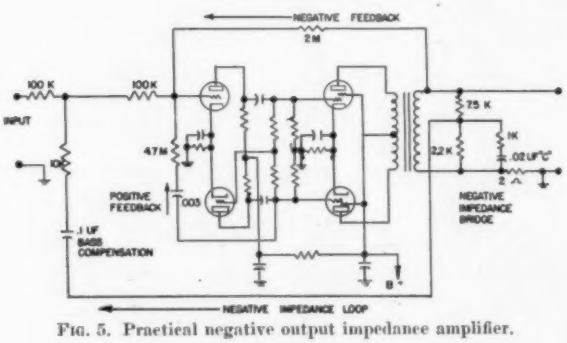

FIG. 5. Practical negative output impedance amplifier.

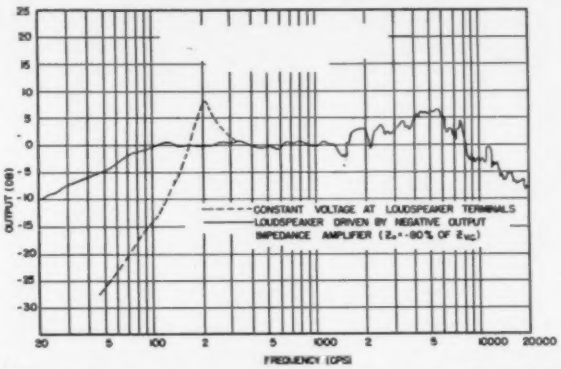
CONSTANT VOLTAGE AT LOUDSPEAKER TERMINALS
LOUDSPEAKER DRIVEN BY NEGATIVE OUTPUT IMPEDANCE AMPLIFIER (Z₀=-80% OF Z_VC)
OUTPUT (DB)
FREQUENCY (CPS)

FIG. 6. Response-frequency characteristic on axis. *RCA SL-12* loudspeaker in ½ cu ft box.

MEASUREMENTS

An inexpensive amplifier was constructed using a circuit similar to Fig. 5 but without the internal positive and negative feedback circuits aforementioned. The output impedance was adjusted to cancel approximately 80% of the voice-coil impedance of a 12" loudspeaker mounted in a ½ cubic foot box. Sufficient bass compensation was provided

[1] John M. Miller, Jr., *Electronics*, 23, 106-109 (March 1950).

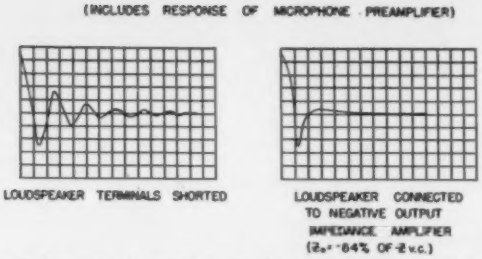
(INCLUDES RESPONSE OF MICROPHONE PREAMPLIFIER)
LOUDSPEAKER TERMINALS SHORTED
LOUDSPEAKER CONNECTED TO NEGATIVE OUTPUT IMPEDANCE AMPLIFIER
(Zo = -64% OF +2 v.c.)

FIG. 7. Response to step function input. *RCA SL-12* loudspeaker in ½ cu ft box.

to extend the response about an octave and a half. The frequency response of the system is shown in Fig. 6 along with the response (dashed line) of the speaker when driven by a constant voltage. Fig. 7 shows the effect on transient response ("hangover") when the negative impedance amplifier is used. To measure distortion, a deluxe amplifier was used incorporating the aforementioned internal positive and negative feedback. Fig. 8 shows the effect of the output impedance upon the distortion at 40 cps when the speaker was mounted in a large (3 cubic foot) box. It is apparent that non-linear flux density is a minor menace since the distortion reaches a minimum at 100% cancellation of the voice-coil impedance.

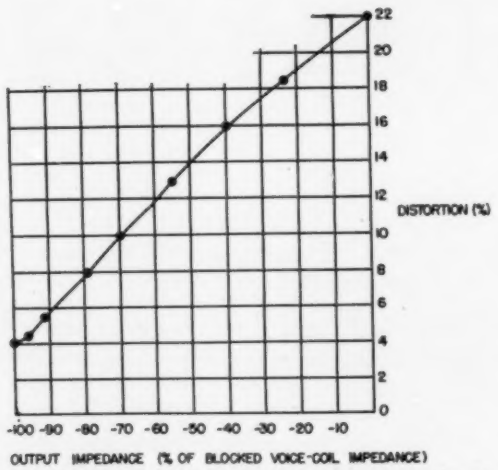

FIG. 8. Total harmonic distortion *vs* amplifier output impedance. Four watts at 40 cps into *RCA SL-12* loudspeaker in 3 cu ft box.

We have seen that a negative impedance amplifier can produce a useful improvement in loudspeaker performance. The improvement in response is most pronounced where the enclosure volume is small. The procedures given here will produce the improvement in low-frequency response which is also sought by the use of resonated enclosures and horns. The negative impedance amplifier should be used only with speakers mounted in infinite baffles. With the speaker performance rigidly controlled by the amplifier, acoustical antiresonators and semi-horn enclosures have little effect on the cone motion and their own resonances may become considerably exaggerated.

CONCLUSIONS

Close study of the equivalent circuit of a loudspeaker has led to the conclusion that previous measurements of negative impedance loudspeaker systems limited to negative *resistance* amplifiers produce pessimistically misleading results. The study further discloses that suitable cancellation of the voice-coil inductance and compensation for radiation characteristics should prove the worth of a negative impedance speaker system. Careful laboratory measurements support this theory in full.[2]

[2] Results of additional measurements on negative impedance-speaker systems have been published. See R. E. Werner, *J. Acoust. Soc. Am.*, **29**, 335-340 (1957).

THE AUTHORS

Mr. Werner received his A.B. degree in electrical engineering from Cornell, in 1950. After graduation, he served for three years with the Navy, engaged in electronics. He joined RCA in 1953, to engage in development and design of commercial microphones and other transducers. His original work in the field of negative impedance amplifiers dates from 1949; a paper on that subject was delivered at the Second International Congress on Acoustics in 1956. His works have been published in the *Journal of the Acoustical Society of America*, in the *Journal of the Audio Engineering Society*, and in *Broadcast News*. He is a member of the Acoustical Society of America and of the Audio Engineering Society.

Mr. Carrel graduated from Iowa State College. Joining RCA after graduation, he worked on the development and design of military communications systems, military and commercial microphones, acoustic instrumentation and electromechanical speech-multiplexing devices. He has presented papers at the meetings of the Acoustical Society of America and the Second International Congress on Acoustics. His writings have appeared in *Broadcast News*, the *RCA Engineer* and in our own *Journal*. He is a member of the Institute of Radio Engineers and of the Acoustical Society of America.

New Developments in Output-transformerless Amplifiers*

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An 11-watt audio power amplifier is described incorporating combined positive and negative feedback. The use of a Sinclair-Peterson type single-ended push-pull output stage enables an 800-ohm loudspeaker to be directly driven, providing excellent results.

INTRODUCTION

THE SUBJECT of this paper is an audio power amplifier in which a number of principles have been combined to obtain very good performance at a reasonable price. The principles themselves are not new, but the combination has led to results which certainly may be called interesting.

First, a brief review will be given of the reasons that led us to the use of single-ended push-pull circuits and the development of a high impedance loudspeaker. The suitability of this system for a combination of positive and negative feedback will be discussed. Detailed circuits are shown and a method for calculation of the distortion figures will be indicated, first for a simplified circuit, and then for the amplifier as it has been built.

The measurements and curves obtained will be exhibited and discussed.

SINGLE-ENDED PUSH-PULL AMPLIFIER AND HIGH IMPEDANCE LOUDSPEAKERS

For a considerable time our laboratory has been trying to improve the reproduction quality of our radios and radiograms, if possible, without increasing the cost.

One of the greatest problems in the mass production of radios, which, in view of competition, simply have to be low cost, is the output transformer. The size of this component seems to be the subject of a continuous struggle between the commercial and the technical staff. It should be mentioned here that as the requirements for frequency characteristic and low distortion figures go up, the size and the price of the output transformers in conventional circuits rise out of proportion, even to a point where the output transformer alone costs more than the rest of the amplifier. The output transformer has finally been eliminated. This has been made possible by the application in radio receivers of a high impedance loudspeaker in combination with a single-ended push-pull output stage.

As is well known this circuit (Sinclair-Peterson) has the property of requiring a relatively low load impedance, (Figs. 1a, b, c, and d).

When power tubes are used of the low anode voltage type as required for ac-dc sets, this load impedance can be still lower.

A special tube (EL86 or 6CW5) has been developed in Holland for this purpose; special insofar as it has been designed with a 6.3 v heater, and when used in a single-ended push-pull arrangement, requires a load impedance of only 800 ohms. With an output stage of such low load impedance it did not seem impossible to produce a loudspeaker with a voice coil of this impedance instead of the usual 2 to 16 ohms.

Theoretically, of course there is no reason why this could not be done; the solution being merely the substitution of a large number of fine gauge windings for a relatively small number of windings using a thicker wire.

In practice, however, there are several difficulties: the insulation thickness becomes of increasing importance when thinner wire is used and the fine wire is more difficult to handle in the manufacturing process. Eventually, these problems were solved and now loudspeakers with "Hi-Z" voice coils have been in production for several years.

In this way an ideal combination was born: a single-ended push-pull output stage directly feeding the loudspeaker. It was not very difficult to build a complete amplifier around this combination. The cheapest circuit we used contained a pre-amplifier, driving the grid of the lower output tube, the grid of the upper output tube being driven and biased by the voltage over a resistor R_d between the cathode of this tube and the anode of the lower one, (Fig. 2). No phase inverter being necessary, the difference in price between a

* Received September 30, 1957. Delivered by Mr. Rodrigues de Miranda before the Ninth Annual Convention of the Audio Engineering Society, New York, October 12, 1957.

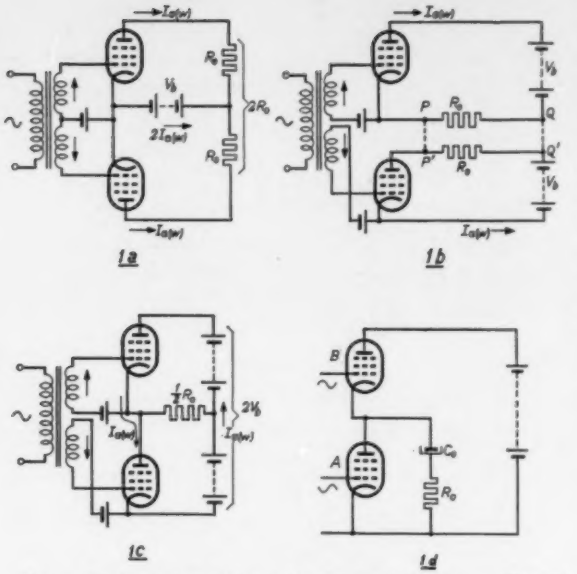

FIG. 1. Derivation of single-ended push-pull circuit. *a.* Normal push-pull arrangement. *b.* Circuit which is equivalent to *(a)*: when PP' and QQ' are connected the single-ended push-pull (SEPP) is obtained. *c.* Single-ended push-pull circuit requiring a load which is only $\frac{1}{2}$ R_a instead of 2 R_a, and where no dc flows through the load. *d.* SEPP circuit where no center-tap on the voltage source is required; in series with R_a a capacitor C_o of high capacity is connected.

conventional amplifier (consisting of a triode, output transformer and speaker) and the simple single-ended version is small, as the output transformer is replaced by a pentode and an electrolytic capacitor. The price difference today between a normal and a high impedance loudspeaker is negligible. The performance, however, of the OTL stage is considerably better. No loss in bass nor in treble, no distortion due to an output transformer, and, in addition, reduction of even harmonics because of the push-pull character of the output stage all in the bargain. This simple circuit does not fall under the category "Hi-Fi" but it looked promising.

There is one special technical feature brought about by the absence of an output transformer: the complete audio amplifier has the character of a resistance-capacitance-coupled amplifier and consequently has much less phase shift between output and input than when transformer coupling is used somewhere in the circuit and this seemed interesting from a feedback point of view. As a matter of fact a more elaborate circuit, complete with phase inverter and negative feedback gave excellent results. However, as sensitivity drops at the same rate as feedback is increased, we decided to use positive feedback in the preamplifier in combination with overall negative feedback. This procedure has been proposed by F. B. Llewellyn and others, and results in a substantial reduction in the loss of sensitivity.

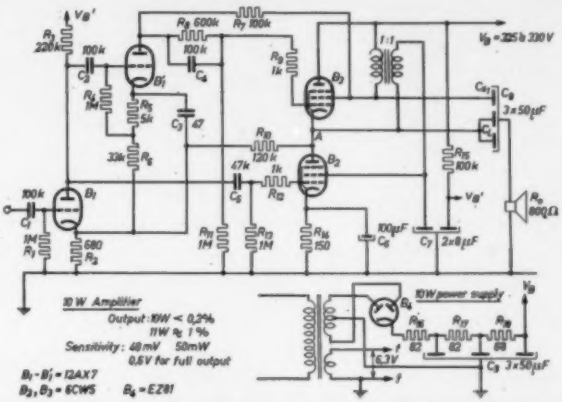

FIG. 3. Complete circuit diagram of a 10w amplifier with choke-feed to screens.

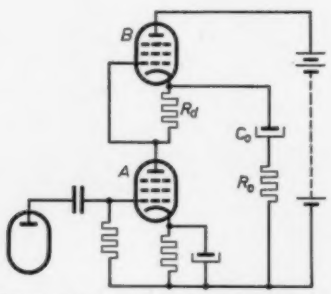

FIG. 2. SEPP circuit where no phase inverter is necessary, the driving voltage (and grid bias) for tube B being obtained from the potential difference across resistor R_d.

A circuit of this kind has in general the disadvantage of being very sensitive to phase shift but as no output transformer is used in this circuit no difficulties in this aspect were expected and in practice we did not encounter any instabilities.

COMBINATION OF POSITIVE AND NEGATIVE FEEDBACK

The principles of this method can be described as the equal division of the distortion percentage between power stage and preamplifier.

The reality, however, is rather complex but nevertheless the results are remarkable especially considering the rather intricate way the circuit has to be built up.

In Fig. 3 the complete diagram is given. The general outline of the circuit is as follows. The first half of the tube B_1 acts as a preamplifier and the voltage developed across the plateload resistor R_3 is applied to the grid of the power pentode B_2. The voltage across R_3 is also applied to the

grid of the second half of B_1 which operates as a phase inverter. The voltage across the anode load R_7 of this half is applied to the grid of the tube B_3.

The load R_9 is connected between ground and A (the common point of cathode and anode of B_2 and B_3), in series with capacitor C_L. The output tubes each require an anode voltage of 160 v and a current of 75 ma (operated in class A). The required load per tube is 1600 ohms, resulting in a combined load of 800 ohms. A speaker with a voice coil impedance of this value is used.

DETAILS OF THE CIRCUITRY

a. Driving voltage for the grid of the upper power tube

If the voltage applied to the grid of the lower 6CW5 is V_2 and the output voltage of this tube is V_0 then the voltage to be applied between the grid of the upper 6CW5 and ground is $V_2 + V_0$. The phase inverter therefore has to deliver a larger voltage than the output tubes.

To avoid voltage overload of the phase inverter the anode voltage of this tube is taken from the screen of the upper tube which, due to C_s, has full output voltage. In this way the voltage over R_7 can be much more equal to V_2, only the feedback caused by the grid bias arrangement has to be taken into account.

b. The screen supply

For the type of output tube used in this circuit the screen must be approximately at anode dc potential, but of course it must have cathode voltage in so far as ac is concerned.

For the lower tube the required dc potential could be obtained from B+ through a voltage reducing resistor. The drawback is then, that the screen voltage decreases with increasing output, due to the increasing screen current under these circumstances. On the other hand, the screen obviously cannot be connected directly to the anode. The same applies to the screen of the upper tube. In both cases a voltage-dropping resistor between anode and screen decreases the maximum output. If this resistor is too high, it lowers the screen dc potential considerably; if it is too low it bypasses the load. A workable compromise can be found which results in a good amplifier—however, with less output power than the theoretical maximum (Fig. 4), and with the added disadvantage that the loudspeaker has to be connected to B+.

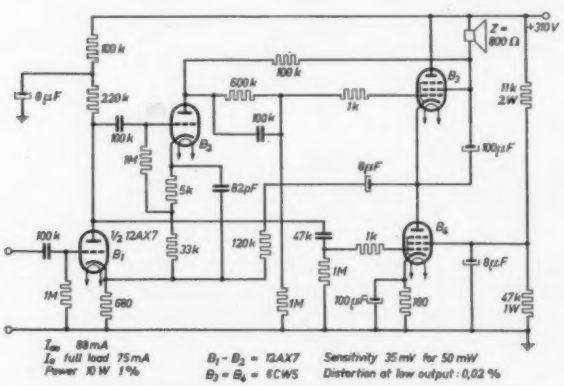

FIG. 4. Complete circuit diagram of a 10w amplifier with resistance-feed to screens.

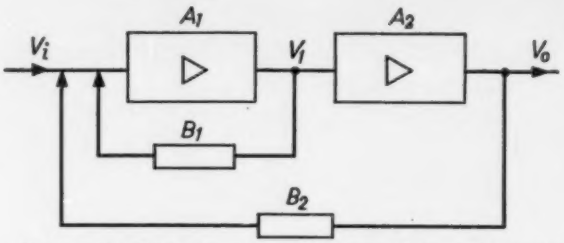

FIG. 5. Simplified circuit of combined positive and negative feedback.

A better solution is to use a choke in each screen supply lead. The advantage is very high anode efficiency of the output stage. At first sight the drawback of the choke is that its self-inductance is in parallel to the resistive output load. This decreases the performance at very low frequencies, partly due to current by-pass and the lowering of the resultant load, and partly due to losses in the choke. But because this noticeable drop in performance only occurs at frequencies below 20 cps this drawback is of no importance and therefore the double choke method was used in our set-up. The two chokes can be combined on one core, which has the advantage that the dc magnetizing forces then counter-balance. With a relatively small core a high inductance (60 h) can be easily obtained.

c. The feedback loops

Perhaps the most interesting point of this amplifier is the combination of positive and negative feedback.

To obtain positive feedback the cathodes of the two halves of the 12AX7 have a common resistor (R_2) to ground. To obtain negative feedback the cathode end of R_2 is connected through a suitable resistor (R_{10}) directly to the output. We shall see that by choosing the proper amount of positive and negative feedback extremely low distortion figures can be obtained.

CALCULATION OF DISTORTION

a. Simplified circuit with positive and negative feedback

For a simplified circuit with combined positive and negative feedback the possibility of obtaining low distortion can be found as follows (Fig. 5).

A_1 and A_2 in Fig. 5 represent two amplifiers in cascade, *e.g.* a pre-amplifying stage and an output stage, whose am-

plification will likewise be called A_1 and A_2 respectively. A portion B_1V_1 of the output signal V_1 of A_1 is fed back to the input of A_1, and a portion B_2V_0 of the output signal V_0 of A_2 is likewise fed back to the input of A_1. If V_i is the signal to be amplified, we may write, quite generally,

$$V_1 = A_1 (V_i + B_1V_1 + B_2V_o)$$

and

$$V_o = A_2V_1.$$

The overall amplification A is accordingly:

$$A = \frac{V_o}{V_i} = \frac{A_1A_2}{1 - A_1B_1 - A_1A_2B_2} = \frac{A_1A_2}{N},$$

where

$$N = 1 - A_1B_1 - A_1A_2B_2.$$

The total distortion D is given by

$$D = \frac{1}{N} D_1 + \frac{1-A_1B_1}{N} D_2 + \frac{1-A_1B_1}{N} D_1D_2$$

where D_1 and D_2 are respectively the distortion of either amplifier. It can be seen that if A_1B_1 is made unity, a very special situation arises: D is reduced to D_1/N, *i.e.* the distortion of amplifier A_2 does not contribute at all to the total distortion. The remaining distortion D_1/N is determined by the (slight) distortion D_1 of the first amplifier and by the quantity N, the latter becoming $-A_1A_2B_2$ for $A_1B_1 = 1$. The absolute value of $A_1A_2B_2$ may be considerably larger than unity, in which case the total distortion D will even be appreciably smaller than D_1. Also, the absolute value of the total amplification A becomes equal to $1/B_2$ (and therefore independent of A_2).

The condition $A_1B_1 = 1$ can be fulfilled for a wide frequency range if A_1 and B_1 are real in that range, *i.e.*, if the amplifier A_1 and the feedback circuit B_1 contain no phase-shifting elements. In the preamplifying stage this condition may be closely approached without much difficulty. The condition $A_1B_1 = 1$ means that the amplifier A_1 is given such a positive feedback B_1 that it is on the verge of oscillating. This does not necessarily mean that the combination A_1–B_1–A_2–B_2 (Fig. 5) is unstable; if the second amplifier and the feedback circuit are free of any elements causing adverse phase shifts, the whole circuit can be kept stable by applying a certain negative feedback B_2. An output transformer is an element which inevitably causes such phase shifts that the stability would be seriously jeopardized.† Only by its elimination it is possible to realize stable circuits of the type considered here.

b. Exact calculation of the actual circuit as shown in Fig. 3

The circuit used here is rather complicated due to the various feedback loops which are interconnected in such a way that the circuit cannot be cut open anywhere without altering the whole system. A new method to calculate the amplification and the harmonics generation of complicated circuits has been found for the case that no phase shift occurs. To calculate the distortion percentage each tube characteristic is usually given in the form:

$$i_a = \alpha V_g + \beta V_g^2 + \gamma V_g^3 + \dots$$

in which V_g is the total driving voltage. But the calculation becomes much simpler if the relation between V_g and i_a for each tube is given in the form

$$V_g = a\, i_a + b\, i_a^2 + c\, i_a^3 + \dots,$$

the coefficients a,b,c, etc being easily derived from α,β,γ, etc.

The method proceeds as follows: For each tube the anode ac current i_K is introduced as the unknown quantity. The network configuration being known, the driving voltage V_K for each tube can then be expressed in the unknown currents and the input voltage V_0. The network being assumed as a linear one, the derived expressions for V_K are linear functions of i_K with coefficients depending on the network elements and having the dimensions of a resistance. If the input voltage is connected only to the first tube we get a family of equations with the general form as follows: (Fig. 6).

$$\left.\begin{aligned} V_1 &= r_{11}\, i_1 + r_{12} i_2 + r_{13} i_3 + \dots\dots r_{1n} i_n + \lambda V_0 \\ V_2 &= r_{21} i_1 + r_{22} i_2 + r_{23} i_3 + \dots\dots r_{2n} i_n \\ V_n &= r_{n1} i_1 + r_{n2} i_2 + r_{n3} i_3 + \dots\dots r_{nn} i_n \end{aligned}\right\} A$$

n is the number of unknown anode currents

For i_k we write $V_k = a_k i_k + b_k i_k^2 + c_k i_k^3 + \dots$ and substituting this in equations A:

$$\left.\begin{aligned} r_{11} i_1 + r_{12} i_2 + r_{13} i_3 + \dots\dots r_{1n} i_n + \lambda V_0 &= a_1 i_1 + b_1 i_1^2 + c_1 i_1^3 + \dots\dots \\ r_{21} i_1 + r_{22} i_2 + r_{23} i_3 + \dots\dots r_{2n} i_n &= a_2 i_2 + b_2 i_2^2 + c_2 i_2^3 + \dots\dots \\ r_{n1} i_1 + r_{n2} i_2 + r_{n3} i_3 + \dots\dots r_{nn} i_n &= a_n i_n + b_n i_n^2 + c_n i_n^3 + \dots\dots \end{aligned}\right\} B$$

Now, if we please which occurs all currents can be developed as real power series in V_0:

$$i_k = x_k V_0 + y_k V_0^2 + z_k V_0^3 + u_k V_0^4$$

FIG. 6

Introducing these series developments for i_K in equation B and equating the coefficients of the same power of V_0 in the left and in the right hand member of each of the equations leads to the following group of families of equations: (Fig. 7).

$$\left.\begin{aligned} (r_{11} - a_1)\, x_1 + r_{12} x_2 + r_{13} x_3 + \dots\dots r_{1n} x_n &= -\lambda_1 \\ r_{21} x_1 + (r_{22} - a_2) x_2 + r_{23} x_3 + \dots\dots (r_{2n} x_n) &= 0 \\ r_{n1} x_1 + r_{n2} x_2 + r_{n3} x_3 + \dots\dots (r_{nn} - a_n) x_n &= 0 \end{aligned}\right\} C$$

$$\left.\begin{aligned} (r_{11} - a_1)\, y_1 + r_{12} y_2 + r_{13} y_3 + \dots\dots r_{1n} y_n &= b_1 x_1^2 \\ r_{21} y_1 + (r_{22} - a_2) y_2 + r_{23} y_3 + r_{2n} y_n &= b_2 x_2^2 \\ r_{n1} y_1 + r_{n1} y_2 + r_{n3} y_3 + (r_{nn} - a_n) y_n &= b_n x_n^2 \end{aligned}\right\} D$$

$$\left.\begin{aligned} (r_{11} - a_1)\, z_1 + r_{12} z_2 + r_{13} z_3 + r_{1n} z_n &= 2b_1 x_1 y_1 + c_1 x_1^3 \\ r_{21} z_1 + (r_{22} - a_2) z_2 + r_{23} z_3 + r_{2n} z_n &= 2b_2 x_2 y_2 + c_2 x_2^3 \\ r_{n1} z_1 + r_{n2} z_2 + r_{n3} z_3 + (r_{nn} - a_n) z_n &= 2b_n x_n y_n + c_n x_n^3 \end{aligned}\right\} E$$

FIG. 7

† The output transformer can be kept outside the feedback loop B_2, but the distortion introduced by it remains undiminished in the output signal; above this the degree of negative feedback is necessarily limited owing to the phase shift between primary voltage and primary current.

We have to realize that if for instance we know that the output current i_{out} is the sum of (as in this amplifier) i_3 and i_4, and once X_3, Y_3, Z_3 and X_4, Y_4 and Z_4 are known, we have the exact relation between i_{out} and V_0, giving amplification, 2nd and 3rd harmonics of the output current.

Now $X_1, X_2 \ldots X_n$ can be calculated from group C
$Y_1, Y_2 \ldots Y_n$ can be calculated from group D
$Z_1, Z_2 \ldots Z_n$ can be calculated from group E, etc.

The advantage of this method is that we have obtained groups of equations of which the left hand sides have in each case the same coefficients, which makes a relatively rapid calculation possible. Now we return to the actual circuit and write down the terms of the determinant: (Fig. 8).

$$\begin{vmatrix} -(R_2 + \frac{R_1}{\mu_1} + a_1) & -R_2 & \epsilon R_0 & -\epsilon R_0 \\ -(R_2 + R_3) & -(R_2 + R_5 + R_6 + \frac{R_7}{\mu_2} \cdot \frac{R_{11}}{R_7 + R_{11}} + a_2) & (\epsilon - \frac{R_{11}}{R_7 + R_{11}} \cdot \frac{1}{\mu_2}) R_0 & -\left(\epsilon - \frac{R_{11}}{R_7 + R_{11}} \cdot \frac{1}{\mu_2}\right) R_0 \\ -R_3 & 0 & -a_3 & 0 \\ 0 & -\frac{R_7 R_{11}}{R_7 + R_{11}} & \frac{R_7 R_{11}}{R_7 + R_{11}} & -\frac{R_7 R_{11}}{R_7 + R_{11}} - a_4 \end{vmatrix}$$

FIG. 8

Here ϵ is the feed-back factor, $R_2/(R_2 + R_{10})$, whilst a_1, a_2, a_3 and a_4 are the reciprocals of the transconductances of the corresponding tubes. By substituting the numerical values it is possible to calculate output current and output voltage as a power series of V_0 from which the distortion percentages can easily be derived.

CRITERION FOR LOW DISTORTION

Now it can be shown that there is one minor which is of particular interest because if its value is zero the contribution of the output stage to the distortion disappears. This minor is shown in Fig. 9. It is comparable to the factor $(1 - A_1B_1)$ in the simplified case.

$$\begin{vmatrix} -(R_2 + \frac{R_3}{\mu_1} + a_1) & -R_2 \\ -(R_2 + R_3) & -(R_2 + R_5 + R_6 + \frac{R_7}{\mu_2} \cdot \frac{R_{11}}{R_7 + R_{11}} + a_2) \end{vmatrix}$$

FIG. 9

The actual value of this minor in the circuit of the abovementioned example was 3.5×10^6 which is not exactly zero, but it is the numerator of a quotient, the denominator of which is very much larger and its relative value is so small that the calculated distortion is very low indeed.

FIG. 10. Frequency response curve.

MEASUREMENTS OBTAINED ON A REPRESENTATIVE AMPLIFIER

The measurements confirm the calculations to a high degree.

Fig. 10 shows the frequency response curve, which is substantially flat from 7 cps to 100 kc. At the higher frequencies a gradual roll-off is introduced to eliminate troubles from local strong rf signals.

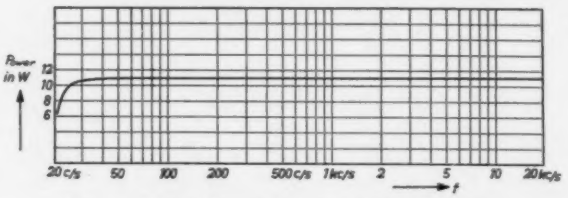

FIG. 11. Power frequency curve at 1% distortion.

Fig. 11 shows the power-frequency curve for 1% distortion. It is substantially flat from 28 cps to well above 20 kc; at 1% the output power is 11 watts. Above this frequency no distortion measurements could be made. Fig. 12 shows a family of distortion-power curves with the frequency as parameter (90, 1000 and 10,000 cps). For a distortion of 0.1% the output is 8 w. The output *vs.* input phase shift as a function of the frequency is shown in Fig. 13. The

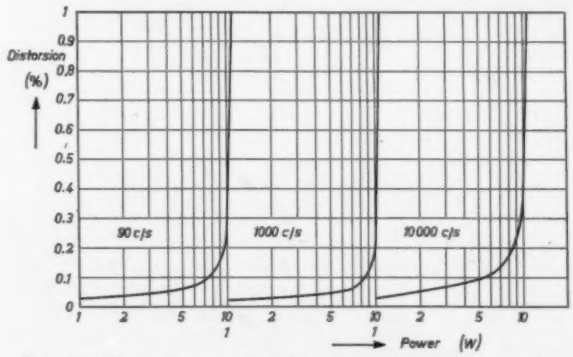

FIG. 12. Distortion as a function of output power at various frequencies.

very smooth curve is characteristic of the absence of transformers. The transient response characteristics are very good as Fig. 14 shows.

ADDITIONAL DATA

To obtain maximum output an input of 0.6 volt is required. The internal output resistance of the amplifier is

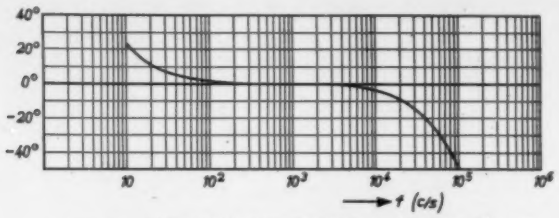

FIG. 13. Phase shift characteristic (output/input).

20 ohms which, compared to a load of 800 ohms, gives a damping factor of 40. The anode current consumption is 75 ma at 325 v.

It should be mentioned that special measuring techniques had to be developed for measuring these low values of distortion. It is of practical interest that this power amplifier is a kind of unit, the properties of which are determined by the type of circuitry more than by the component values. Even the sensitivity cannot be changed very much because the negative feedback is effective for dc too, limiting the maximum value of this feedback. The output power can easily be multiplied by a factor 2, 3, etc. On the other hand it may be preferred to use several complete amplifiers plus loudspeakers, making the circuit very flexible, and adaptable for stereophonic reproduction.

CONCLUSION

Summarizing the results we can give the following: The amplifier consists of 15 resistors, 5 paper capacitors, 6 electrolytic capacitors, 1 small double choke, a 12AX7 and two 6CW5.

The amplifier delivers 11 watts at 1% distortion over the whole frequency range (28 to 20,000 cps) into a load of 800 ohms. At 0.2% distortion the output is 10 watts, and at 0.1% distortion 8 watts, over this frequency range.

The frequency characteristic is flat from 7 cps to 50 kc $\pm$ ½ db. Transient response is excellent, intermodulation distortion is very low (at 8 watts $<0.5\%$ for 40 and 10,000 cps at 4 : 1). The sensitivity is 0.6 volts for full output. The damping factor is 40, the anode efficiency 50%—the theoretical limit for a class-A push-pull arrangement.

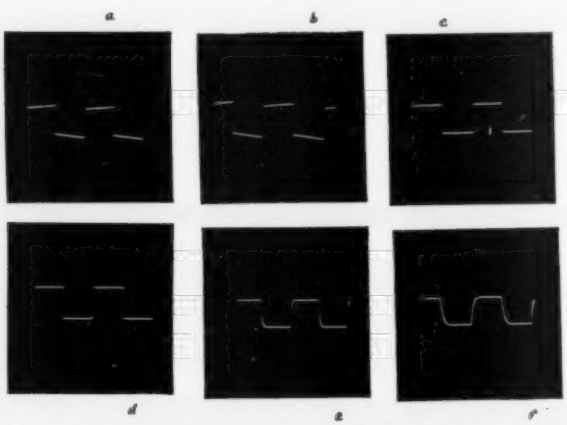

FIG. 14. Transient response with square wave input. *a*. 60 cps half output. *b*. 60 eps full output. *c*. 1000 eps full output. *d*. 1000 eps 10% overload. *e*. 10 ke full output. *f*. 20 ke full output.

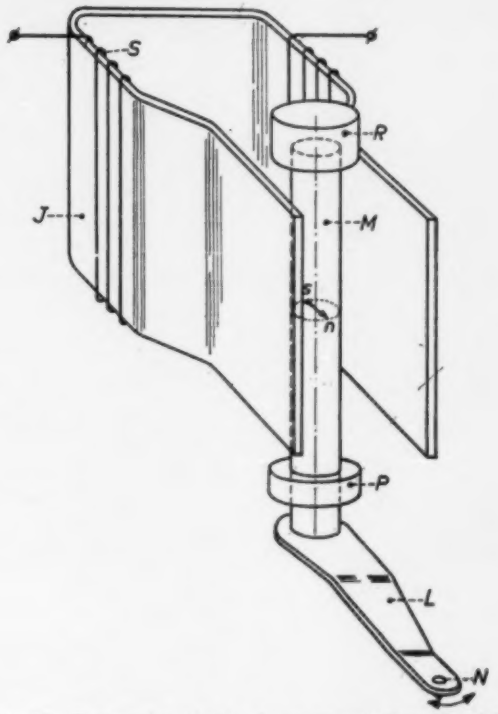

FIG. 15. Construction sketch of the magneto-dynamic pick-up head.

Some particulars about the auxiliary equipment:

The preamplifier has been carefully designed; the distortion at a voltage necessary for full output of the power amplifier does not exceed 0.02%.

The pick-up is of a magneto-dynamic construction as shown in Fig. 15. The armature is a thin rod *M* (0.8 x 12 mm) of ferroxdur magnetized perpendicular to its axis (*s* – *n*). It is turned by a small lever *L* actuated by a diamond stylus *N*. This rotation introduces a varying flux in the core *J* which results in a corresponding voltage being developed in coil *S*. The compliance of the system is very high, with the mass and the distortion being exceptionally low.

The loudspeaker is a dual-cone type with an 800 ohm voice coil, air-cushion damped at the low-frequency end. It

has a practically flat impedance curve to the high end of the frequency spectrum.

The enclosure is novel also. It is a double unit: a small one hardly larger than the speaker, with a built-in acoustical resistance and an acoustical mass, mounted in an outer enclosure. This is more or less comparable to a bass-reflex cabinet. The remarkable property—the one we aimed at—is that the electrical impedance of this combination in the neighborhood of the resonance frequency remains constant. In this way also the current through the voice coil is kept to the same value even in the "resonance" region—if the word resonance may still be used here—resulting in a very smooth bass response.

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The Audio Engineers Exhibit and Tenth Annual Convention of the Audio Engineering Society

THE Audio Engineering Society's first Exhibit of Professional Audio Equipment, and the Tenth Annual Convention of the Society, will be held September 29 through October 3, 1958 at the Hotel New Yorker, 34th Street and Eighth Avenue, New York City.

Marking the tenth consecutive annual meeting of the Society, more than 70 papers will be read at this five-day session. This is by far the largest number of technical papers dealing exclusively with audio engineering that has ever been presented at one gathering, and eloquently reflects the present high degree of interest in audio.

In addition, this year, the Society is sponsoring its first Exhibit in which equipment of interest primarily to the engineer will be displayed. Fifteen prominent manufacturers and distributors, some of whose advertisements appear in this issue, are participating in this initial event.

The complete program of events and papers:

9:00 A.M. *Monday, September 29, 1958*
REGISTRATION—Entrance Grand Ballroom

10:00 A.M. *Monday, September 29, 1958*
THE TRANSISTOR IN AUDIO CIRCUIT APPLICATIONS
Chairman: F. M. Dukat, Engineering and Product Manager, Semiconductor Division, Raytheon Manufacturing Company, Boston, Mass.

DIRECT-COUPLED TRANSISTOR-TUBE AUDIO AMPLIFIER FOR RADIO AND TV

WILLIAM F. PALMER and G. SCHIESS
Sylvania Electric Products, Inc., Semiconductor Division, Woburn, Mass.

A two-stage, direct-coupled, hybrid audio amplifier is described which is comparable in cost and performance with its all-tube counterpart.

Power for the transistor stage is derived from the cathode of the tube, the grid of which is directly coupled to the collector of the transistor. Bias-point stabilization is achieved by applying 100% d.c. feedback around both stages. This is also consistent with minimal component costs, as both tube and transistor stages mutually share certain components.

It is believed that such simplified circuits point the way toward the early use of transistors in line-operated television and radio receivers, etc. Performance of the hybrid amplifier has been shown to be satisfactory over the normal operating temperature range of such receivers.

APPLYING THE TRANSISTOR IN A STEREOPHONIC TAPE SYSTEM

DWIGHT V. JONES, *Application Engineer,*
General Electric Company, Syracuse, N. Y.

A complete semiconductor, stereophonic tape playback system is described. The transistor applications in each individual circuit will be discussed. The individual direct coupled three-stage preamplifiers will accommodate most of the tape head impedances that are commercially available. The preamp has low distortion and a good signal-to-noise ratio. Each power amplifier performs with either an 8 or 16 ohm speaker system and can be powered with a range of supply voltages from 30 to 50 volts. (Demonstration scheduled.)

A 25-WATT HIGH QUALITY TRANSISTORIZED AUDIO FREQUENCY POWER AMPLIFIER

R. MINTON
Radio Corporation of America, Semiconductor and Materials Division, Somerville, N. J.

This paper will describe a completely transistorized 25-watt, high quality sound system consisting of a preamplifier, amplifier and speaker operating from a variable reluctance pick-up. The preamplifier is equalized for the standard RIAA record characteristic and contains the usual bass, treble and loudness controls. (Demonstration scheduled.)

DESIGN OF A STEREO CONTROL CENTER

PAUL A. GRACE, *Applications Engineer,*
Semiconductor Division, Raytheon Manufacturing Company, Newton, Mass.

This paper describes a stereo preamplifier circuit which has equalized inputs for magnetic and crystal phono cartridges, and flat inputs for tuners and auxiliary equipment. This paper discusses suitable equalizers, amplifiers, level and tone controls.

1:30 P.M. *Monday, September 29, 1958*
STEREO PERCEPTION
Chairman: H. E. Roys, Manager, Engineering, Record Division, RCA Victor, Indianapolis, Indiana

PSYCHOLOGICAL FACTORS GOVERNING THE BINAURAL EFFECT

JOHN A. COOLEY
Georgetown University, Washington, D. C.

This paper discusses the factors relating to the perception of sound depth in stereophonic reproduction. The psychological effect of phase displacement, direction and intensity are related to the stereophonic illusion. Graphs and charts for practical application are given.

BROADENING THE AREA OF STEREOPHONIC PERCEPTION

B. B. BAUER
CBS Laboratories, Division of CBS, Inc., New York, N. Y.

One of the limitations of conventional stereophonic loudspeakers is the narrow area within which optimum stereophonic perception is achieved. An "Isophonic" loudspeaker system is described which broadens the area of optimum stereophonic perception to include practically all of the useful room area. The paper will be followed by a demonstration.

PSYCHOACOUSTICS APPLIED TO STEREOPHONIC REPRODUCTION SYSTEMS

P. C. GOLDMARK, B. B. BAUER and J. M. HOLLYWOOD
CBS Laboratories, a Division of CBS, Inc., New York, N. Y.

Psychoacoustic studies in average-size rooms have shown that the frequencies of the Left and Right channels may be mixed below 250 cps, suitably delayed, and reproduced with a single loudspeaker, without change of stereophonic perspective. The Left and Right channels above 250 cps may then be reproduced with small unobtrusive loudspeakers with considerable increase in flexibility and saving in cost. The high frequency L and R loudspeakers may be small Isophonic loudspeakers which combined with the "mixed lows" scheme provide a small, wide area stereophonic sound source ideal for home use. The paper will be followed by a demonstration.

STEREO AS AN INTEGRAL SYSTEM

NORMAN E. CROWHURST
Audio Design Services, Whitestone, N. Y.

Confused and often conflicting advice based on differing experience can arise from failure to interrelate studio microphone technique and listening facilities as components of an integrated system. (Demonstration scheduled.)

DETERMINING THE AREA OF STEREO PERCEPTION

ABRAHAM B. COHEN, *Director,*
Advanced Acoustics Company, New York, N. Y.

Stereo perception depends upon the synthesis of sound fields radiated by multiple sources. The integration of these fields on the basis of the beamed or dispersed fields of the respective sound sources leads to predictable areas of stereo perception.

7:30 P.M. — *Monday, September 29, 1958*
MUSIC AND ELECTRONICS
Chairman: **Professor Vladimir Ussachevsky, Department of Music, Columbia University, New York, N.Y.**

SEVERAL PROBLEMS IN MUSICAL ACOUSTICS

PROFESSOR MELVILLE CLARK, JR.
Massachusetts Institute of Technology, Cambridge, Mass.

Certain problems in the realm of musical acoustics are stated together with the reasons for their special study. Such study, now made possible by a grant from the National Association of Music Merchants, may concern itself with the problems of: the cues used to identify the instrument sounding musical tone; the elements distinguishing the tone produced by a chorus of instruments sounding one note from that produced by one instrument; and the musical environment.

SPECIALIZED EQUIPMENT USED AT COLUMBIA UNIVERSITY STUDIO FOR THE PRODUCTION OF TAPE MUSIC

PETER MAUZEY
Department of Electrical Engineering, Columbia University, New York, N. Y.

Many varieties of electronic and electromechanical apparatus have been used in experimental music studios throughout the world. Some of the most useful devices are standard commercial equipment; others have been specifically designed and constructed for the use of composers. This paper will describe such special apparatus in use at the Electronic Studio-Laboratory, Columbia University.

SOUND SYNTHESIS BY THE USE OF MAGNETIZED ARRAYS

A. H. FRISCH
Bar Building, New York, N. Y.

Description of a method of manually arranging cylinder-shaped iron rods of uniform diameter which, when applied to magnetic tape and magnetized manually by a permanent bar magnet, will record a musical tone of predictable fundamental frequency; technique for similar arrays varying the fundamental and harmonics; musical scales and harmonics; vibrato effects; varying the form of attack; the use of this method of synthesis with multiple track recording and some possible applications.

MUSICAL TIMBRE MUTATION BY MEANS OF THE "KLANGUMWANDLER", A FREQUENCY TRANSPOSITION DEVICE

PROFESSOR VLADIMIR A. USSACHEVSKY
Department of Music, Columbia University, New York, N. Y.

A uniform shift in the frequency of all the harmonics in any sound can be achieved by a device named "Klangumwandler", which was developed for this purpose by Dr. L. Heck and Mr. F. Burek of the Southwest German Radio. This shift affects frequency ratios among the harmonics with the resultant radical changes in timbre. The main features of this device are described; a sound demonstration of the results obtained by the author will suggest certain possible applications in the field of music and acoustics.

GENERATION OF MUSIC BY A DIGITAL COMPUTER

H. V. MATHEWS and N. GUTTMAN
Acoustics Research Department, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

Since sound waves can be produced by means of a digital-to-analog converter operating on a sequence of numbers generated by a general purpose digital computer, it is possible to program the computer to produce any sound. The potentialities of such a program for creating both conventional and new music are discussed.

POSSIBILITIES FOR COMBINING ELECTRONIC MUSIC, TAPE MUSIC AND MUSIQUE CONCRETE WITH TRADITIONAL MUSIC

PROFESSOR OTTO LUENING
Department of Music, Columbia University, New York, N. Y.

Within the traditional framework of instrumental or vocal music can now be admitted a new wealth of sound material, developed in the experimental studios by heterogeneous techniques of sound mutation and synthesis. A tape recorder sometimes is called upon to become an instrument in an orchestra. Examples will be presented of works by composers Ussachevsky and Luening with additional references to composers B. Maderna, P. Boulez, L. Berio, H. Baddings, Edgar Varese and others.

9:30 A.M. — *Tuesday, September 30, 1958*
DISK RECORDING AND REPRODUCTION
Chairman: **H. E. Roys, Manager, Engineering, Record Division, RCA Victor, Indianapolis, Indiana**

FROM STEREO TAPE TO STEREO DISK

ALBERT B. GRUNDY, JR.
International Electro-Acoustic Corp., New York, N. Y.

A description of the design and operation of a complete stereo tape to stereo disk recording system and accompanying reproducing system. Attention will be given to such features as advance head pickup on the tape playback for continuous variable pitch control.

A NEW MASTER DISK RECORDING LATHE FOR STEREO DISK USE

STEPHEN F. TEMMER
Gotham Audio Development Corp., New York, N. Y.

This will describe the newly designed Neuman AM-32b disk mastering lathe; four-speed synchronous motor, with the ZS stereo disk cutter; automatic previewed pitch control and separate automatically previewed depth of cut and depth-pitch integration. (Demonstration.)

A NEW STEREO FEED BACK CUTTERHEAD SYSTEM

REIN NARMA, *Chief Engineer,*
Fairchild Recording Equipment Corp., Long Island City, N. Y.

The design and development of a new Double Moving Coil Stereo Cutter System, describing many revolutionary techniques as part of an engineering program in designing this system.

CHECKING THE AXES OF OPERATION OF STEREO CUTTER CHANNELS

H. G. REDLICH
Teldec, Berlin, Germany

This paper describes a new optical device for the scanning and measurement of groove modulation amplitudes and instantaneous cutting velocities of 45/45 stereo records.

RECENT DEVELOPMENTS IN STEREOPHONIC DISK RECORDING

C. C. DAVIS and DR. JOHN FRAYNE
Westrex Corporation, Hollywood, California

This paper describes developments in stereophonic disk recording for the interval between its first demonstration before this Society in October 1957 and the present time.

THE TELDEC MINIATURE STEREO CUTTERHEAD SYSTEM

STEPHEN F. TEMMER, *President,*
Gotham Audio Development Corporation, New York, N. Y.

This will be a survey of activities in Europe in the past year in the field of stereo disk cutting and reproduction, with descriptions of the two Ortofon stereo cutters and special emphasis and construction details on the soon-to-be introduced TELDEC cutterhead. (Demonstration scheduled.)

1:30 P.M. *Tuesday, September 30, 1958*
DISK RECORDING AND REPRODUCTION

Chairman: Benjamin B. Bauer, Vice President, CBS Laboratories, New York, New York

SOME THOUGHTS ON GEOMETRIC CONDITIONS IN THE CUTTING AND PLAYING OF STEREO DISKS AND THEIR INFLUENCE ON THE FINAL SOUND PICTURE

C. R. BASTIAANS
N. V. Philips, Eindhoven, The Netherlands

The influence of various geometric conditions in the cutting and reproducing process is investigated. It is found that stylus contour plays no important role; axis orientation does play a role. The nature of sound picture distortion caused by such cross-modulation is investigated (panoramic distortion), phase relationship of cross-modulation components causing increase or decrease in width of the sound picture (width distortion).

A STEREOPHONIC VARIABLE RELUCTANCE PHONOGRAPH CARTRIDGE

PETER E. PRITCHARD
Specialties Electronic Components, General Electric Company, Auburn, N. Y.

A variable reluctance cartridge for stereophonic use is described having a smooth frequency response, wide channel separation and low distortion. The principles of operation are discussed and comparative data on actual performance is given.

THE DEVELOPMENT OF A HIGH QUALITY STEREOPHONIC PICKUP CARTRIDGE

WALTER O. STANTON, *President,*
Pickering & Company, Plainview, Long Island, N. Y.

The characteristics that must be embodied in a stereophonic phonograph cartridge are described, and a development program is detailed which has produced a cartridge meeting all the objectives of the design.

A SINGLE ELEMENT STEREO CARTRIDGE

JOHN F. WOOD, *Chief Engineer—Cartridges,*
Electro-Voice, Inc., Buchanan, Michigan

A survey of the Westrex 45/45 Stereo disk system is presented with particular emphasis on the design requirements for stereo cartridges. The principle of operation of a one-piece ceramic element, sensitive to displacement in two coordinates, is described. This element, a small cylinder with electrodes disposed about its inner and outer surfaces, is mounted in a plug-in type housing for ease of conversion and stylus replacement. Special damping and mounting methods are utilized to obtain proper values of vertical and lateral response and impedance. The paper is concluded with performance data on response, distortion, compliance and isolation.

A CONSTANT DISPLACEMENT STEREO CARTRIDGE

WILLIAM S. BACHMAN
Columbia Records, Inc., New York, N. Y.

The constant displacement cartridge to be described consists of two coplanar ceramic elements driven by an orthogonal lever. Each ceramic element produces an independent output in response to 45/45 modulations. The moving system has a low mass and a high compliance, and produces constant displacement operation throughout the audio range.

THE DEVELOPMENT OF A DOUBLE ROTATING COIL PICKUP

REIN NARMA, *Chief Engineer,*
Fairchild Recording Equipment Corp., Long Island City, N. Y.

This paper describes the development of a double rotating coil phono pickup cartridge for stereo records and general problems of monogroove stereo record reproduction.

7:30 P.M. *Tuesday, September 30, 1958*
THE STEREO LISTENER'S NEEDS (Symposium)

Chairman: R. D. Darrell, Stone Ridge, New York, Contributing Editor, High Fidelity Magazine and Audiocraft Magazine

The stereo listener's needs and interests as viewed by a representative group of panelists from the many fields encompassing high fidelity recording and reproduction.

Because of the tremendous general interest in stereo, this session will be open to non-members of the Society and to those who are not registered for the entire convention. Special entrance fee for the symposium will be $1.00.

HAROLD LAWRENCE, *Musical Director,*
Classical Division, Mercury Records, Inc.

G. E. FOSTER
Newark College of Engineering

JAMES CARROLL, *Manager—Audio Department,*
Harvey Radio Company, New York, N. Y.

CHESTER SANTON
Radio Station WQXR, New York, N. Y.

Following the presentations above there will be an open forum.

9:30 A.M. *Wednesday, October 1, 1958*
MAGNETIC RECORDING TAPE, THE MEDIUM

Chairman: Walter H. Erikson, Defense Products Department, Radio Corporation of America, Camden, N. J.

AN INVESTIGATION OF MAGNETIC TAPE DROP-OUTS

ROBERT H. CARSON
U. S. Naval Research Laboratory

A drop-out classifier and counter has been developed which simultaneously counts the number of drop-outs in 12 different classifications. Three variable amplitude thresholds and four variable time gates can be used. Data concerning the drop-out distribution both as to amplitude reduction and to length will be discussed.

50 "MYLAR" T—A FILM ESPECIALLY DESIGNED FOR USE AS A MAGNETIC TAPE BASE

LESTER R. BARTON
Film Department, E. I. du Pont de Nemours & Company, Inc., Wilmington, Delaware

The properties of 50 "Mylar" T polyester film are presented and compared with other films used in the manufacture of magnetic tape. Selected physical properties of magnetic tape produced on a base of 50 "Mylar" T will be compared with magnetic tapes on bases of "Mylar" and cellulose acetate.

MAGNETIC TAPE RECORDING WITH LONGITUDINAL OR TRANSVERSE OXIDE ORIENTATION

RICHARD F. DUBBE, *Technical Service Engineer,*
Magnetic Products Laboratory, Minnesota Mining and Manufacturing Co., St. Paul, Minn.

A comparison of the performance of magnetic tape when the recording field is in the same direction as, or perpendicular to, the oxide particles as encountered in magnetic disk or video recording.

THE NOISE IN MAGNETIC RECORDING WHICH IS A FUNCTION OF TAPE CHARACTERISTICS

PHILIP SMALLER, *Staff Physicist,*
Ampex Corporation, Redwood City, California

The noise in magnetic recording can be divided into background noise and modulation noise. Background noise for a particular tape can be represented by a power spectrum which is independent of the method by which the noise is reproduced. Modulation noise can be conveniently divided into amplitude modulation and frequency modulation noise. The advantages of such a division are discussed.

SIGNAL TO NOISE PROBLEMS AND NEW EQUALIZATION FOR MAGNETIC RECORDING OF MUSIC

JOHN G. MCKNIGHT, *Senior Engineer,*
Ampex Corporation, Redwood City, California

General problems in defining and measuring signal to noise ratio for high quality music recording, and an improvement in the subjective signal to noise ratio of the magnetic recorder obtained with a new equalization. There will be a demonstration on the new AME equalization.

A NEW DEVICE FOR THE REDUCTION OF PRINT-THROUGH

FRANK RADOCY, *Quality Engineer,*
Audio Devices, Inc., New York, N. Y.

The "Echoraser" is a static device designed to reduce the intensity of layer to layer signal transfer or print-through. Up to 18 db reduction in print has been achieved.

1:30-4:00 P.M. *Wednesday, October 1, 1958*
MAGNETIC RECORDING TECHNIQUES AND EQUIPMENT

Chairman: Walter H. Erikson, Defense Products Department, Radio Corporation of America, Camden, N. J.

EVOLUTION OF A SUCCESSFUL SPRING DRIVEN BROADCAST QUALITY TAPE RECORDER

ALBERT C. TRAVIS, JR.
Broadcast Equipment Specialties Corp., Beacon, N. Y.

The paper covers motion problems of spring driven motors, an unusual low friction tape transport, a miniature flutter filter, design criteria for dry battery operated recording amplifiers and coming developments.

MAGNETIC RECORDING OF AUDIO FREQUENCIES

CHESTER E. BEACHELL
National Film Board of Canada, Montreal, Canada

Pre- and post-equalization limitations, the effects of bias frequency, bias current to recording current ratios, methods of injection and phenomena related to wave length versus head contact affecting low frequency response, and effects of replay head loading are discussed and illustrated as observed in the development of the Sproketape magnetic recording system.

ELECTROMAGNETIC EFFICIENCY OF MAGNETIC RECORDER HEADS

MARVIN CAMRAS, *Senior Physicist,*
Armour Research Foundation, Chicago, Illinois

A simple method is described of obtaining a figure of merit for response of magnetic recorder heads due to core losses and electrical characteristics.

FACTORS AFFECTING HIGH FREQUENCY RESPONSE AT LOW TAPE SPEEDS

R. J. YOUNGQUIST
Magnetic Products Division, Minnesota Mining and Manufacturing Co., St. Paul, Minn.

A discussion of the effects of head and tape characteristics as they affect short wave-length response at low tape speeds.

9:00 A.M. *Thursday, October 2, 1958*
ANNUAL BUSINESS MEETING, INSTALLATION OF OFFICERS, COMMITTEE REPORTS

9:30 A.M. *Thursday, October 2, 1958*
MAGNETIC RECORDING—NEW DEVICES

Chairman: Walter H. Erikson, Defense Products Department, Radio Corporation of America, Camden, N. J.

HIGH QUALITY REPRODUCTION OF MAGNETIC TAPE IN A CARTRIDGE

D. R. ANDREWS, *Project Engineer,*
Radio and Victrola Division, RCA Laboratories, Cherry Hill, New Jersey

A magnetic tape system using lower speed and narrower tracks without sacrificing response is combined with the operation of the tape in a cartridge or magazine to provide a low cost, high quality, more convenient product.

A MAGNETIC HEAD FOR STEREO OR HALF TRACK ON ONE-EIGHTH INCH TAPE

H. RAY WARREN, *Development Engineering,*
Defense Electronics Products, Radio Corporation of America, Camden, New Jersey

This paper describes the design and development of a magnetic record-reproduce head for magnetic tape. Tape width: ⅛ inch, Number of Channels (in-line gaps): 2, Cross-talk isolation: Better than 55 db, Frequency response: 15 KC (with normal equalization); Tape speed: 3¾ IPS.

PROFESSIONAL HIGH SPEED DUPLICATION OF THE NEW FOUR-TRACK STEREO TAPES

R. J. TINKHAM
Audio Products, Ampex Corporation, Redwood City, California

Recent improvements in the basic art of tape recording have made possible even greater economies in the sale of professionally recorded tapes. These improvements are outlined and their application to bi-directional two-channel stereotapes is described. The equipment for processing masters to over-the-counter tapes, and some of the problems involved are also described.

A MAGNETIC DISK RECORDING AND REPRODUCING SYSTEM

GEORGE A. SINGER, *Broadcast Studio Engineering,*
Industrial Electronic Products, Radio Corporation of America, Camden, New Jersey

Pre-grooved disks, molded from a dispersion of iron oxide in an elastomer over an aluminum core combine the advantages of magnetic recording with the handling ease of disks.

The system is designed specifically to handle manually or automatically the numerous short selections in a broadcast program.

A MAGNETIC HEAD FOR GROOVED MAGNETIC RECORDING DISKS

H. RAY WARREN, *Development Engineering,*
Industrial Electronic Products, Radio Corporation of America, Camden, New Jersey

This paper describes the design and development of a magnetic record-reproduce head for operation with magnetic grooved disks.

Design considerations such as, extremely narrow track (.005"), maintaining medium-to-head contact, cross-talk due to closely spaced grooves and head wear are covered.

PROPERTIES AND PERFORMANCE OF MAGNETIC RUBBER RECORDING BELTS

WILLIAM FABING and R. R. HARTEL, *Magnetic Section,*
Clevite Electronic Components Division, Clevite Corporation, Cleveland, Ohio

Rubber and neoprene belts and disks are coated or impregnated with magnetic oxide to provide a recording medium with long wear characteristics and magnetic qualities adequate for many recording applications.

1:30-4:00 P.M. *Thursday, October 2, 1958*
MEASUREMENTS AND STANDARDS IN AUDIO
Chairman: Sheldon I. Wilpon, Audio Communications Section, Materials Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

THE AUTOMATIC PLOTTING OF CARTRIDGE RESPONSE

C. P. Germano, *Section Head—Transducers,*
Clevite Electronic Components, Cleveland, Ohio

A constant amplitude (piezoelectric ceramic) stack driven by an RIAA compensated signal over the audio range is utilized in combination with a graphic recorder to automatically plot ceramic phonograph cartridge response.

STANDARDS—STEPCHILD IN THE LABORATORY

Charles E. White, *Chief, Laboratory Services Section,*
The Avco Manufacturing Company, Lawrence, Massachusetts

Significant psychoacoustic reactions: high fidelity equipment performance measurements; loudspeaker acoustic responses—all are "authoritatively" expressed by measurements indicating high resolution. Is the measuring equipment capable of supporting conclusions drawn?

THE ARP 2—A NEW INSTRUMENT FOR SOUND MEASUREMENT

Louis W. Erath, *Vice President,*
Research and Development, The Southwestern Electronics Company, Houston, Texas

A new portable instrument has been developed which automatically plots an audio response curve for the purpose of analyzing the acoustical conditions in a room or auditorium. It will detect anomalous conditions which should be considered before an installation of sound equipment is made. The instrument may also be used to test the sound systems after the installation.

DETERMINATION OF ABSOLUTE RECORDING SENSITIVITY OF MAGNETIC TAPE

E. D. Daniel and I. Levine
National Bureau of Standards, Washington, D. C.

A method has been developed for measuring two anhysteretic magnetic constants of the oxide coating. The coating thickness and recording gap-length are the only additional parameters necessary to determine the absolute bias for maximum output and the absolute recording sensitivity expressed as the ratio of remanent induction in the coating to field strength deep in the recording gap.

6:00 P.M. *Thursday, October 2, 1958*
TENTH ANNUAL BANQUET—Presentation of Awards
Terrace Room, Hotel New Yorker
(Cocktails 6:00 p.m., Banquet 7:00 p.m.)

9:30 A.M. *Friday, October 3, 1958*
AUDIO APPLICATIONS
Chairman: S. E. Sorenson, Columbia Records, Inc., New York, N. Y.

AUDIO APPLICATIONS — INDUSTRY

SELECTIVE PAGING BY MEANS OF AUDIO FREQUENCIES

Louis E. Philipps
Auth Electric Co., Inc., Long Island City, N. Y.

Selective pocket pagers add third dimension to loudspeaker paging systems. Technical discussion of selective audio induction system and means of combining the two.

BREAKING THE INDUSTRIAL SOUND BARRIER

S. Leibowitz
Electronic Engineering Company, Akron, Ohio

The purpose of this paper is to present a minimum of technical data and a maximum of empirical demonstrations of actual noise conditions encountered in heavy industry, to provide intelligible speech communication.

AUDIO APPLICATIONS — BROADCASTING

STEREOPHONIC BROADCASTING BY FM MULTIPLEX METHOD

William S. Halstead, Multiplex Service Corp., New York, N. Y.
Richard Burden, Burden Associates, Mt. Kisco, N. Y.

The paper reviews the development of multiplex stereocasting, beginning with first experimental transmissions in 1950. The major portion of the paper relates to a system of multiplex stereo broadcasting in which one subchannel plus main channel is employed for stereo, and a second subchannel for subscription music.

PERFORMANCE CHARACTERISTICS OF FM MULTIPLEX STEREO TRANSMISSION

Murray G. Crosby, *President,*
Crosby Laboratories, Inc., Syosset, N. Y.

Measurements on typical FM tuners in conjunction with a stereo FM Multiplex adapter are given which show the signal-to-noise ratio characteristics of the main channel, the sub-carrier channel, and the stereo channel. These data are given for the standards which provide the optimum performance of an FM station as a stereo broadcasting station and also for the proposed systems which apply to sub-carrier channels, one of which provides stereo information and the other a subsidiary communications channel.

Recommended standards with respect to program crest factor, pre-emphasis tolerance and modulation monitoring are given for the compatible system using optimum standards.

AUDIO APPLICATIONS — AMPLIFIERS

STABILITY CONSIDERATIONS IN HIGH FIDELITY AMPLIFIERS

George H. Grenier, *Advanced Product Engineer,*
High Fidelity Components Engineering, General Electric Co., Auburn, N. Y.

The paper will outline a practical procedure of avoiding oscillations and/or instability in high gain feedback amplifiers. Pertinent mathematics will be separately appended.

SINGLE PUSH-PULL STAGE AMPLIFIERS FOR STEREOPHONIC SOUND REPRODUCTION

B. B. Bauer, CBS Laboratories, A Division of CBS, Inc.
W. S. Bachman, Columbia Records, Inc., New York, N. Y.
J. Hollywood, CBS Laboratories, Division of CBS, Inc.
G. Maerkle, CBS Laboratories, Division of CBS, Inc.

By using a self-matrixing input stage, and matrixing output transformers a single push-pull output stage may be caused to amplify two independent stereophonic signals. The principles and design features of such an amplifier will be described and demonstrated.

DESIGNING A MULTI-PURPOSE STEREO PRE-AMPLIFIER

Ir. J. Rodrigues de Miranda
N. V. Philips, Eindhoven, The Netherlands

In between the required sensitivity and the required output voltage the stereo preamplifier should be designed with a good tone and volume control system. Logical design leads to a pre-amplifier with distortion as low as 0.03% for all frequencies.

1:30 P.M. *Friday, October 3, 1958*
STUDIO AND SPEECH INPUT EQUIPMENT
Chairman: Philip Erhorn, Audiofax, Inc., Stony Brook, L. I., New York

A THREE-CHANNEL STEREOPHONIC SOUND REINFORCEMENT MIXING CONSOLE

Philip Erhorn
Audiofax, Inc., Stony Brook, Long Island, N. Y.

Described is a self-contained unit of unusual scope designed for either stereo or single coverage of large public or private gatherings. The design includes many features which make the work of the

operator less complicated. Push button switching flexibility of all inputs and outputs plus unusual emergency facilities afford a completely versatile console with no obvious limitations for future applications.

AN AUDIO CONSOLE DESIGNED FOR THE FUTURE

A. C. Angus
General Electric Company, Electronics Park, Syracuse, N. Y.

Complete transistorization of all amplifiers plus a new plug-in module design makes the new General Electric BC-21-A audio console a marked departure from past designs.

MULTI-CHANNEL STEREOPHONIC MIXER CONSOLE

William H. Miltenburg
RCA Victor Record Division, New York, N. Y.

A description of a sixteen position, four channel, mixer-console combining echo, equalization, reverberation, gain reduction and echo mixer in one complete unit.

A PACKAGED EQUIPMENT FOR THE PRODUCTION OF TRUE REVERBERATION

Wilhelm Franz, Elektromesstechnik, Lahr, Schwarzwald
V. J. Skee, Electronic Applications, Inc., Stamford, Connecticut

Unit developed by Dr. Kuhl of the Rundfunktechnisches Institute of West Germany. A metal plate dynamically excited and associated contact pickup system with calibrated damping expressed in reverberation time is described in terms of its electro-acoustic characteristics.

THE DEVELOPMENT AND APPLICATION OF SYNTHETIC REVERBERATION SYSTEMS

Lewis S. Goodfriend, Montclair, New Jersey, and
John H. Beaumont, Vanguard Recording Society, New York, N.Y.

Reverberation is an essential element of audio program material. This paper traces the historical and engineering development of synthetic reverberation systems from the echo chamber through acoustical and electromechanical devices to the modern re-entrant magnetic tape reverberation generator. The use of multiple heads with electronic re-entry; the need for non-integral spacing of heads and extremely flat electronic frequency response in magnetic tape systems are analyzed. (Demonstration scheduled.)

A DEFINITIVE LOUDSPEAKER SYSTEM FOR MONITORING IN CONTROL AND AUDITION ROOMS

Wilhelm Franz, Elektromesstechnik, Lahr, Schwarzwald
V. J. Skee, Electronic Applications, Inc., Stamford, Connecticut

High quality monitor system developed by Dr. Enkel of the West Deutsch Rundfunk of West Germany. The techniques used in the Model 084 loudspeaker with constant pressure spherical sound radiation, with consideration of the factors of radiation resistance, distortion, iteration and adjustment.

6:15 P.M. *Friday, October 3, 1958*

LOUDSPEAKERS—DESIGN AND APPLICATION

Chairman: Abraham Cohen, Director, Advanced Acoustics Company, New York, N. Y.

TWO NEW HORNS AND DRIVERS COVERING HIGH FREQUENCIES

S. E. Levy, E. Matsuoka and V. Brociner
University Loudspeakers, Inc., White Plains, N. Y.

One speaker, designed around a two-inch voice coil, drives a throat labyrinth from the concave side of a diaphragm. This covers midrange and highs. The other designed with a three-quarter inch voice coil drives a labyrinth from the convex side to cover high frequencies. Construction and performance data will be shown.

ANALYSIS OF A LOW FREQUENCY LOUDSPEAKER SYSTEM

Peter W. Tappan, *Senior Research Engineer,*
The Warwick Manufacturing Co., Chicago, Illinois

A method is shown for calculating approximate low frequency response and selecting enclosure dimensions of a reflexed loudspeaker system employing a folded tube.

THE USE OF SUBJECTIVE MEASUREMENT SCALES IN AUDIO ENGINEERING

Richard E. Liebich
Stromberg-Carlson Company, Rochester, N. Y.

The familiar Fletcher-Munson loudness contours will be reviewed and compared with other loudness contour data. A new form of these data will be presented to facilitate application by audio engineers. The qualities of pitch, volume, fatigue, timbre, attack, decay and perspective will also be discussed.

INTERMODULATION DISTORTION TESTING OF LOUDSPEAKERS

Leroy J. Malmsten
Stromberg-Carlson Company, Rochester, N. Y.

Existing intermodulation distortion test methods and modifications of these techniques applicable to loudspeaker evaluation will be reviewed. In particular, the relative significance of various test methods will be discussed.

PERFORMANCE OF ENCLOSURES FOR LOW RESONANCE HIGH COMPLIANCE LOUDSPEAKERS

James F. Novak, *Senior Design Engineer,*
Jensen Manufacturing Company, Chicago, Illinois

This paper presents a generalized theory on design and performance of vented loudspeaker enclosures, including the special case of the pressure-tight closed box.

Excellent response, high output and low distortion can be realized to very low frequencies.

A method is described for design of small enclosures with super-low resonance high compliance loudspeakers.

Inherent interrelationships of the speaker-amplifier system Q, efficiency and response balance are shown, with application to commercial designs.

A NEW WIDE ANGLE DIRECT RADIATOR TWEETER

Adelorie F. Petrie, *Product Engineer,*
High Fidelity Loud Speakers, General Electric Company, Auburn, N. Y.

A new wide angle direct radiator tweeter which has unusually flat frequency response from 1 KC to above 15 KC is described. The fundamental principles of operation and basic limitations of direct radiator, horn and electrostatic tweeters are compared.

THREE NEW HIGH EFFICIENCY SPEAKERS FOR P.A. USE

S. E. Levy, G. Sioles, R. Carlisle and B. Sharp
University Loudspeakers, Inc., White Plains, N. Y.

The first speaker is effective for the speech range (above 500 cycles), the second reproduces speech and music (above 150 cycles) and the third is especially suitable for music (above 60 cycles) and covers speech also. Construction and performance data to be furnished.

A NOVEL COMPACT FLEXIBLE STEREO SPEAKER SYSTEM

Emanuel Berlant
Stephens-TruSonic, Inc., Culver City, Los Angeles, California

A simple LC filter network and two compact limited range speakers supplement a standard full range speaker for three-channel reproduction from dual amplifiers. The center channel is controllable for optimum results under various conditions.

A NEW APPROACH TO VENTED CABINET DESIGN

G. Sioles and V. Brociner
University Loudspeakers, Inc., White Plains, N. Y.

A new speaker system using ducted cabinets of novel design, based on analog computer use to determine optimum parameters at very low frequencies.

DEVELOPMENT OF A FULL-RANGE TRANSDUCER ASSEMBLY FOR THE GENERATION OF HIGH INTENSITY SOUND

Richard E. Liebich and John A. King (Paper by John King)
Stromberg-Carlson Company, Rochester, N. Y.

The requirements of the aircraft industry for environmental testing of electronic components in high intensity sound fields have led to the development of a high-energy, full-frequency-range coaxial transducer assembly. The high acoustic output range from 16 to 18,000 cycles is generated by a low frequency cone employing a unique suspension system, a mid-frequency horn-loaded compression driver, and a group of inductively driven high frequency radiators, all mounted symmetrically within a cast metal frame eighteen inches square.

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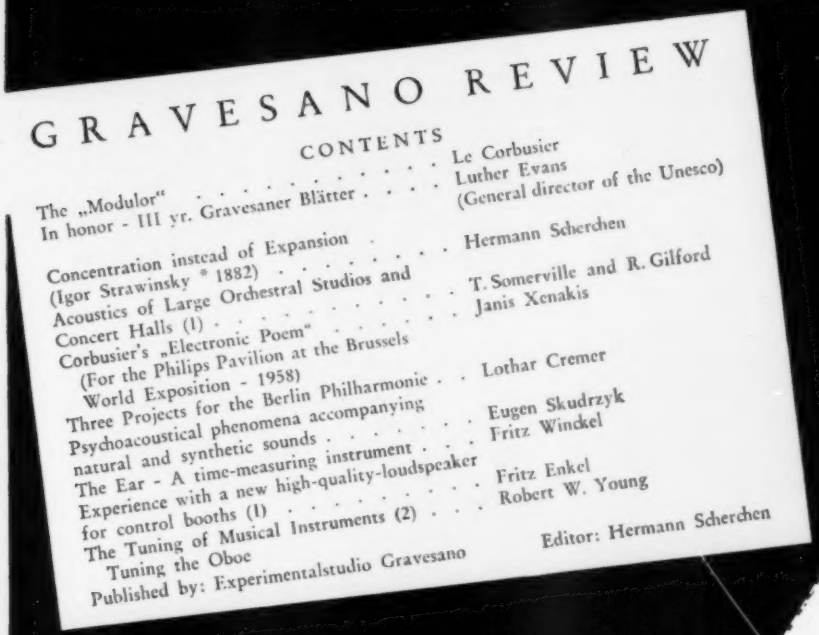

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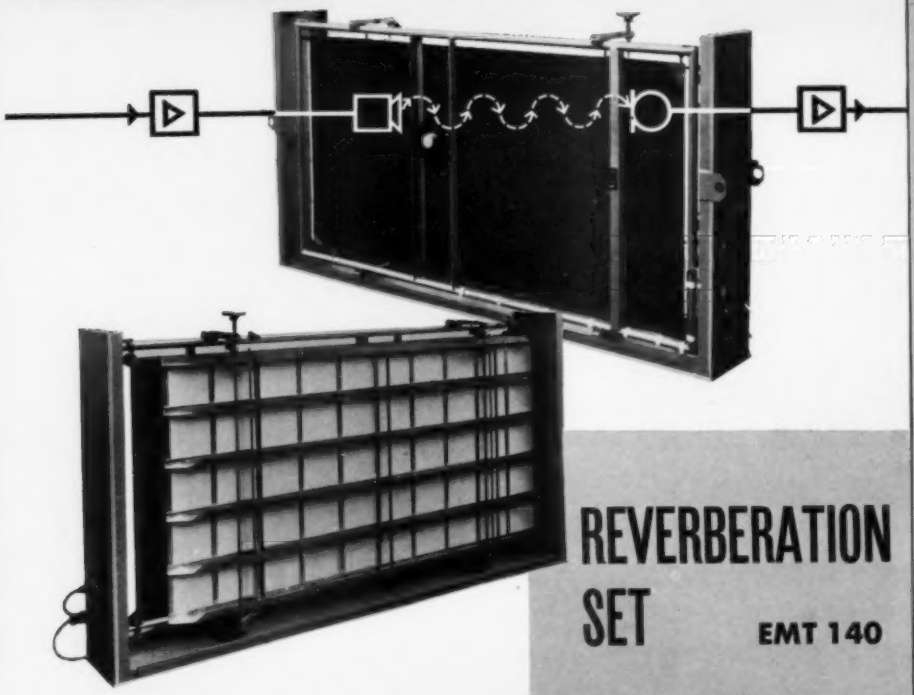

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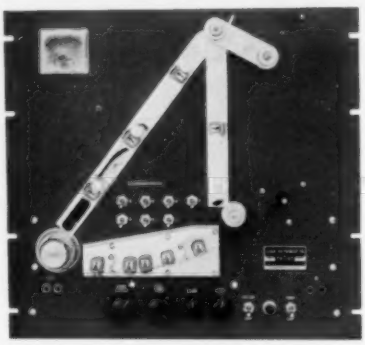

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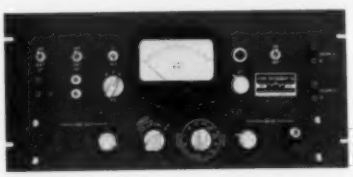

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3 Stock machines selected at random!

Gentlemen:

We have tested the three Garrard Model 301 Turntables which the undersigned selected at random from sealed unopened cartons in your warehouse stock. These three bore the following serial numbers: 867, 937, 3019. We used a standard Model WB-301 mounting base without modification, a Leak tone arm fitted with their LP cartridge, and a complete Leak preamplifier and power amplifier, model TL/10.

Pickup and amplifier system conformed in response to the RIAA-new AES-new NARTB curve within ± 1 db.

Standards referred to below are sections of the latest edition, National Association of Radio & Television Broadcasters Recording and Reproducing Standards. Our conclusions are as follows:

Turntable easily adjusted to exact speed!

Measurements were made in accordance with NARTB specification 1.05.01, using a stroboscope disc. In every case, speed could be adjusted to be in compliance with section 1.05, i.e. within 0.3%. In fact, it could easily be adjusted to be exactly correct.

WOW less than NARTB specifications!

Measurements were made at 33⅓ rpm in accordance with NARTB specification 1.11, which calls for not over 0.20% deviation. These values substantially agreed with those given on Garrard's individual test sheets which are included with each motor.

Garrard Serial No.	%
867	.17
937	.13
3019	.12

Rumble less than most professional recording turntables!

Measurements were made in accordance with sections 1.12 and 1.12.01, using a 10 to 250 cps band pass filter, and a VU meter for indication. Attenuation was the specified 12 db per octave above 500 cps and 6 db per octave below 10 cps. Speed was 33⅓ rpm.

Signal to Rumble Ratio Using Reference Velocity of 7 cm/sec at 500 cps

Rumble: checked by official NARTB standard method (—35 db. min.) —52 db.!

This reference velocity corresponds to the NARTB value of 1.4 cm/sec at 100 cps.

Garrard Serial No.	DB
867	52
937	49
3019	49

The results shown are all better than the 35 db broadcast reproducing turntable minimum set by NARTB section 1.12. In fact they are better than most professional disc recording turntables.

Signal to Rumble Ratio Using Reference Velocity of 20 cm/sec at 500 cps

Rumble: checked by Manufacturer A's methods —61 db.!

Garrard Serial No.	DB
867	61
937	58
3019	58

We include this second table to facilitate comparison because some turntable manufacturers have used their own non-standard reference velocity of 20 cm/sec, at an unstated frequency. If this 20 cm/sec were taken at 100 cps instead, we would add an additional 23.1 db to the figures just above. This would then show serial number 867 to be 84.1 db.

Rumble: checked by Manufacturer B's methods —84.1 db.!

It will be seen from the above that no rumble figures are meaningful unless related to the reference frequency. Furthermore, as stated in NARTB specification 1.12.01, results depend on the equalizer and pickup characteristics, as well as on the turntable itself. Thus, it is further necessary to indicate, as we have done, the components used in making the test. For example, a preamplifier with extremely poor low frequency response would appear to wipe out all rumble and lead to the erroneous conclusion that the turntable is better than it actually is. One other factor to consider is the method by which the turntable is mounted when the test is made. That is why our tests were made on an ordinary mounting base available to the consumer.

Of greatest importance! Always consider these vital factors to evaluate any manufacturer's claim.

Very truly yours,

C. J. LeBel

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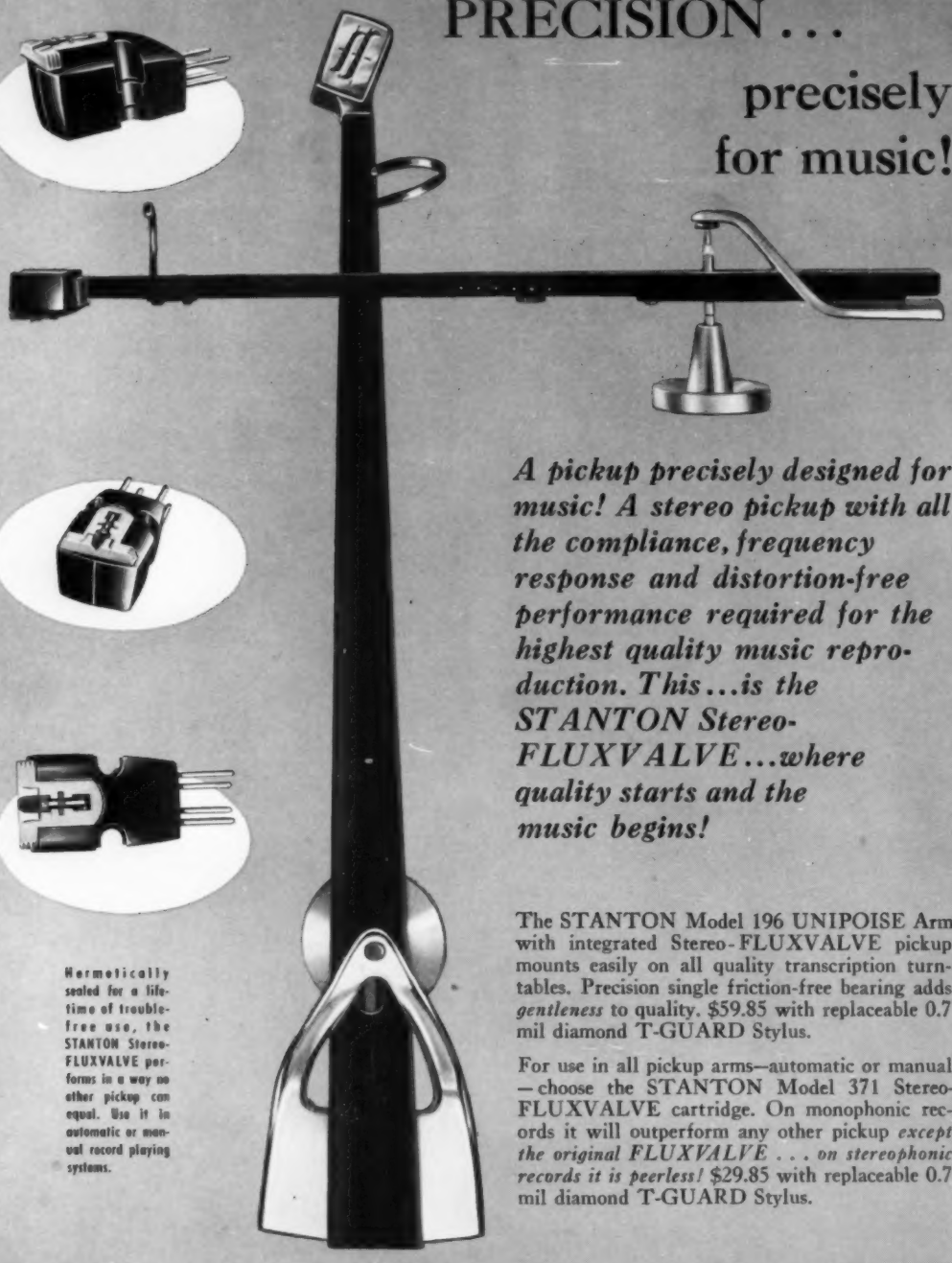

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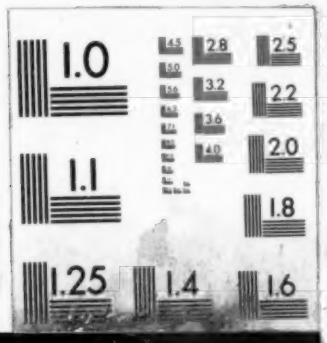
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